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Analysis of Transit Oriented Development Compatibility for Light Rail Station Areas adjacent to U.S. Interstate Freeways

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Analysis of Transit Oriented Development Compatibility for Light Rail Station Areas adjacent to U.S. Interstate Freeways

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ABSTRACT

In 2006, the city of Denver completed a major phase of the T-REX project that included expanding a Light Rail Transit (LRT) system, building 13 stations along the corridors of Interstates 25 and 225. The expansion brought mixed concerns about whether locating the system alongside interstate freeways would produce transit-oriented developments (TOD), or if it intended to have stations that serve multiple purposes, some functioning as destinations and others serving as feeder stations to generate ridership for the system. This prompted a study to (1) create a typology of station areas and determine what type of station areas are located near an interstate freeway and (2) to quantify what aspects of station areas promote ridership within the system, again with a particular focus on those stations adjacent to freeways. We identified numerous geographic variables considered to impact ridership such as land use, socio-economic population features, the street network, and features of LRT stations. We then used factor and cluster analysis on street network and land use data to create typologies of station areas based on these criteria. Of specific interest was whether stations located adjacent to interstate freeways had a unique built environment. We then used multiple regression analysis to estimate potential ridership relating to the built environment as well as the socio-economic and rail station characteristics as independent variables for each station. The overall results provided evidence that station areas near interstate freeways presented a built environment that could limit their ability to transition into a TOD compatible neighborhood.

INTRODUCTION

Over the past several decades, global environmental concerns have underscored the need for society to develop in a more sustainable manner (Intergovernmental Panel on Climate Change, 1995). Twin concerns about greenhouse gas (GHG) emissions and uncertainty about fossil fuel availability in the future associated with growing demand and increasing awareness of the concept of peak oil, has highlighted the need to reduce Vehicle Miles Traveled (VMT) (Transportation Research Board, 2009). VMT is an important variable to consider since vehicle travel accounts for approximately 28% of emissions on average in the United States, with evidence that share is continually increasing (Urban Land Institute, 2009). Policy-makers have placed increasing emphasis on expanding public transportation service in U.S. cities to help mitigate the ill effects associated with automobile-oriented sprawling development patterns that have characterized urban growth in the U.S. (Duane & Malaczynski, 2009; Littman, 2015; The Beacon Hill Institute at Suffolk University, 2008).

The public transportation sector has seen a mode called Light Rail Transit (LRT) revive itself throughout the United States, supported by the Federal Transit Administration's (FTA) New Starts program to fund new and expansion transit systems (*Formally the Urban Mass Transit Administration)*. In return, numerous standard setting bodies such as the American Association of State Highway and Transit Officials (AASHTO), the American Public Transportation Association (APTA), and the Transportation Research Board (TRB) have adapted best practices on a concept called Transit Oriented Development (TOD), through policies to consider when developing communities around this mode of transit to produce impactful ridership. While TOD has yet to gather universally accepted best practices, many of the overall goals from using this planning approach have honed in on creating a compact mix of land uses, designed to encourage pedestrian activity and in return reduce VMT (Leigh & Hoelzel, 2012).

Both government and research professionals have recognized that when LRT implementation culminates through policies that are reflective of TOD best practices, wide ranges of benefits generate an overall improved quality of living including but not limited to VMT reduction, improved air pollution, and traffic congestion relief (Renne & Wells, 2005). The National Cooperative Highway Research Program (NCHRP) found that various policy-makers identified 56 benefits/objectives that TOD could support in neighborhoods, which aligns itself with the notion that TOD provides numerous benefits (Transit Cooperative Research Program, 2004). More importantly, this addresses the interests of multiple stakeholders that seek out different benefits from transit implementation in their various communities. However, an APTA study has recognized that in some cases, these benefits/objectives that drive public support for TOD may lead to LRT implementation in communities whose built environments are poorly conducive with identified TOD best practices (Hemily, 2004) .

We will examine this theory extensively to show that TOD is not a one-size-fits-all approach, which in return will support evidence that there are built environments potentially incapable of producing TOD outcomes where LRT is implemented. This study builds upon a known link between land use and transportation identified by many planners and research institutions that can explain why there may be limitations on TOD outcomes because of the built environment composition (Handy, 2002) . Of particular interest will be how station areas adjacent to freeways are compatible with TOD policies, as we will explain through research why we believe freeways greatly impede pedestrian oriented activity and land use, which are major foundational elements of successful TOD implementation.

This paper looks at the city of Denver as our case study, as they recently installed 13 light rail stations adjacent to Interstate 25 and 225, just south of the Central Business District. Our process will identify the variety of typologies that exist at all the station areas on a system and if there is a presence of a built environment that fits the description of non-compatible TOD that exist frequently at these areas near U.S. Interstates. Given these typologies, we can model it with other factors found to affect ridership volume, and quantify the extent built environments, interstates, and/or other characteristics have on ridership in a transit corridor. This paper contains a review of pertinent literature in section two, the description of study area in section three, data and methodology in sections four and five respectively, results in section six, discussion of results in section seven, and our conclusions in section eight.

LITERATURE REVIEW

TOD Overview

There is no evidence to suggest there has been a universal definition of TOD, as it has often been a reflection of the vision researchers and policy makers hold independently on such design standards (Transit Cooperative Research Program, 2004). In regards to how to design and implement the TOD standards, there is no universal acceptance from various professionals collaborating on what constitutes the perfect TOD blueprint. TOD has been best classified as a design standard under smart growth, summarized by many as focusing on the standard three D's in Density, Diversity, and Design; providing compact, mixed-use, location efficient development that promotes a pedestrian friendly atmosphere adjacent to transit (Cervero & Kockelman, 1997; Dittmar & Ohland, 2004).

The earliest observations surrounding TOD have found planners desiring a wide range of outcomes in adjacent station communities based on uniquely desired objectives and existing environments for different stakeholders. Researchers have concluded that a one-size-fits-all approach is not necessary in any system in order to promote unique places, so long as the unique station areas compliment themselves and utilize the transit system as a foundational transportation asset of the urban realm through their built environments (Renne & Wells, 2005). However at times, the TOD approach focuses too narrowly through strategies such as producing node-like transportation centers or feeder stations for commuters. This can be easily confused with urban centers that have a true sense of place for pedestrian behavior through various activities such as work and recreation (Bertolini & Spit, 1998). Planners have also overlooked place making within the TOD concept by focusing solely on walking buffers, a researched concept that the maximum walking time and distance pedestrians will travel *(2000 feet to a ½ mile)* is the baseline for TOD compatibility, with no regards to the built environment within that identifiable zone (Calthorpe, 1993).

While academia has been able to collaborate towards defining TOD and provide the best insight on TOD practice and its major elements, its interpretation at the planning profession level has continued to shy away from universal comprehension. The Capital Region Council of Government (CRCOG) in Connecticut stated in a collaborative study that TOD is a planning approach that calls for high density, mixed used development, where transit can serve pedestrians (Pierson, 2002). Alternatively, the Denver Regional Council of Government (DRCOG) defines TOD in its *2006 Strategic Plan* as “a mix of uses at various densities within a half mile radius or walking distance, of a transit stop” (Denver Region Council of Governments, 2006, p. 10). While both definitions echo the key concepts that researchers use to illustrate TOD best practices, the discrepancy between various and high density as well as a Euclidian vs. walking distance scale of a TOD buffer are certain examples of parameters that planners have not made universal in TOD policies. This discrepancy could potentially cause varying levels of accuracy in forecasted LRT ridership if there is no comprehension of human behaviors based on the built environment.

While many urban planners have recognized the relationship between transit and land use that TOD standards emphasize, the implementation of LRT in many neighborhoods has not seen this knowledge translate over effectively; mainly due to site location as the American Planning Association found in one case study (Kain, 1990). The Dallas Area Regional Transit (DART) LRT system sheds light on the starvation for ridership that DART and many other transit providers faced when they expected neighborhoods near implemented LRT would rapidly develop from an auto-oriented network to a TOD built environment that supports higher ridership demand. Similar to DART, the Regional Transit District (RTD) in Denver that provides LRT service noted in its 2010 *Strategic Plan for Transit Oriented Development,* a need for more compact development over existing development patterns within a 10-minute walk of transit along with a mix of vertical and horizontal buildings that are pedestrian oriented (Regional Transportation District, 2010). The RTD suggested that some of these station areas were still non-TOD compatible after 15 years of providing transit service to them.

Alternatively, the Chicago Transit Authority (CTA) identifies in its collaborative report, (*Transit Friendly Development Guide*, *2009)* as already operating in a transit-oriented community, with a rich history of transit oriented street networks and developing in areas already with high density to spur its success (Chicago Transit Authority, 2009). This attributes to the fourth highest rail rapid transit ridership in the U.S. and the sixth most walkable city according to walk score, a metric of walkability by neighborhood (Walk Score, 2010). The CTA case study provides strong evidence that failing to place stations where walking and dense infrastructure is presently a feasible option may not optimize TOD outcomes that provide a high catchment of walk and ride users utilizing transit.

Urban vs. Suburban Transit Riders

In 1996, a study by Parsons and Brinckherhoff (P&B) predicted factors that impacted light rail ridership boarding's in U.S. cities, yet failed to consider the spatial scale factor for LRT systems developed in the post-World-War II era (Kuby, Barranda, & Upchurch, 2004). LRT systems in the early 20th century typically developed solely in high-density areas, as "street-cars" operated in the downtowns and the fringe of central business districts (CBD) where all station areas contained similar building densities and mixed uses that were pedestrian friendly. The TCRP found however in its 1996 Report *(Transit and Urban Form)* that modern LRT systems are more expansive than older systems and reach beyond the urban fringe into non-CBD neighborhoods (Transit Cooperative Research Program, 1996). The Annual Review of Sociology found in their respective study that regions beyond the urban fringe called suburban communities, consist mainly of less grid like structured street networks, segregation of neighborhoods by land use types, and sprawl to the extent that the majority of trips are only accessible by automobile (Baldassare, 1992).

As the TCRP found in Report 16, the design of most LRT systems in the latter half of the 20th century facilitate access from suburban developments to the urban core alongside the prominent use of automobiles in these non-CBD neighborhoods. This benefits the suburban community by connecting non-CBD residential districts to jobs and activities in the CBD through feeder stations that likely have parking; comparable to a commuter rail system in larger metropolitan regions like Boston and New York. While FTA recognizes commuter rail as a separate mode from LRT based on vehicle type, an LRT system that reaches suburban communities could disguise itself as a commuter rail system due to its nature of attracting park and riders at feeder stations commuting to the CBD.

This disguised behavior could affect P&B's findings when assessing LRT corridors outside the downtown core, by overlooking concerns regarding walk-ability vs. park and ride stations within these corridors and thus misinterpreting factors of ridership between suburban oriented systems vs. LRT systems only operating within CBD's (Transit Cooperative Research Program, 2003). In accordance with the Transportation Research Board, LRT should function differently than heavy or commuter rail, "*along exclusive rights-of-way at ground level, on aerial structures, in subways, or occasionally, in streets and to board and discharge passengers at track or car floor level.'*"', providing access within the CBD with less impedance on the surrounding environment (Transportation Research Board, 2000, p. 3). The majority of LRT systems instead have produced systems containing stations beyond CBD's where LRT operates at higher speeds with grade-separated guide-way when not operating within a designated downtown network. The function of stations outside the CBD may better represent functions of a commuter rail system given its desire to behave as a hybrid system and feed commuter based trips, which have not been associated as TOD compatible outcomes.

Station Typology and the Built Environment

The distinction between CBD vs. non-CBD stations can best explain itself by assessing the unique composition of the built environments between dense urban and sprawling suburban neighborhoods, sometimes identified through a station typology. Certain regional planners that have pushed transit implementation have recognized the existing variations between urban and suburban, showing through long-range visions the kind of typologies they expect in LRT station areas in future years for their respective regional transit networks. DRCOG is an example of a regional planning organization that collaborates with their respective transit authorities to define a set of typologies, by analyzing the existing conditions of all its current and proposed station corridors to assess what kind of TOD outcomes they would want the system to produce by 2030. They revealed seven different typologies that could characterize the built environments of all the station areas in the system to validate the idea multiple TOD outcomes would produce the best system ridership. Typologies showed a variety of details ranging from desired land use mix and housing types, to proposed scale and system function including amount of park and ride spacing. Figure one shows all these details.

TOD Typology	Desired Land Use Mix	Desired Housing Types	Commercial/ Employment Types	Proposed Scale	Transit System Function
Downtown	Office, retail, residential, entertainment, and civic uses	Multi-family and loft	Prime office and shopping location	5 stories and above	Intermodal facility/transit hub. Major regional destination with high quality feeder bus/streetcar connections.
Major Urban Center	Office, retail, residential, entertainment	Multi-family and townhome	Employment emphasis, with more than 250,000 office & 50,000 sf retail	5 stories and above	Sub-Regional destination. Some Park-n-ride. Linked with district circulator transit and express feeder bus.
Urban Center	Office, retail, residential	Multi-family and townhome	Limited office. Less than 25,000 sf office. More than 50,000 sf retail	3 stories and above	Sub-Regional destination. Some Park-n-ride. Linked with district circulator transit and express feeder bus.
Urban Neighborhood	Residential, neighborhood retail	Multi-family townhome, small lot single-family	Local-serving retail. No more than 50,000 sf	2-7 stories	Neighborhood walk-up station. Very small Park-n-ride, if any. Local bus connections.
Commuter Town Center	Office, retail, residential	Multi-family townhome, small lot single-family	Local and commuter-serving. No more than 25,000 sf	2-7 stories	Capture station for in-bound commuters. Large Park-n-ride with local and express bus connections.
Main Street	Residential, neighborhood retail	Multi-family	Main street retail infill	2-7 stories	Bus or streetcar corridors. District circulator or feeder transit service. Walk-up stops. No transit parking.
Campus/ Special Events Station	University Campus, Sports Facilities	Limited multi-family	Limited office/retail	Varies	Large Commuter destination. Large parking reservoirs but not necessarily for transit.

Figure One: TOD Typologies from the Denver Strategic Plan Manual. (Denver Region Council of Governments, 2006)

Alternatively, Phoenix, Arizona tried to establish TOD compatibility before its LRT inauguration through a concept called Advanced TOD. Rather than zoning for build out of station areas after LRT implementation, Advanced TOD is the creation of a TOD overlay zone at locations near proposed light rail stations ahead of LRT construction that attempts to produce TOD compatible development prior to the inauguration of operation, per a 2010 study (Atkinson-Palombo & Kuby, 2011). The study used typology analysis to provide an inventory of what kind of station typologies existed on the system after implementing advanced TOD zoning in anticipation of new transit service. The results of this study found that not all stations built up in similar ways despite similar zoning implementations. This concluded that neighborhoods along light rail transit stops along a system route would have unique typologies, based on different compositions of the existing built environment prior to the inauguration of transit.

While forecasting future typologies may be effective for planners, it may not consider the impacts the built environment poses to allow a station area to transition easily into these desired typologies that was evident in Phoenix. Overall, the inability to understand the built environment in its existing nature may produce inaccurate estimates of ridership that light rail stations expect to generate overtime, evident earlier from the study on land use forecasting for DART in Dallas. This happens on multiple occasions according to another study, showing that DART along with ten new light rail systems found ridership to be 15-75% below forecasted levels, with no evidence of significant increase in their following years (Pickrell, 1992). Overall, this suggests that planners may be overlooking the existing capacity of transit feasibility in a neighborhood by misunderstanding how key elements of the existing built environment may or may not compliment transit use.

Relationship between Transit and Land Use

In order to understand what makes TOD outcomes feasible in neighborhoods, we must readdress the unique difference between what defines dense urban and sprawling suburban, and what role that plays in producing a pedestrian friendly built environment. Studies have shown that road network design is a foundational concept in a built environment that behave as skeletal bones of a city, in that they are merely permanent in nature and strongly impact the development that is supported by it (Garrick & Marshall, 2009). The study found that lower levels of street connectivity and intersection density led to higher automobile mode shares that tend to cater towards a poor implementation of zoning mixes and parcel sizing that produce non-pedestrian friendly infrastructure in an urbanized setting, such as single family housing and box retail in plazas. This helps support an ongoing theory that overlaying transit onto an urban fabric is not always effective towards producing walkable locations conducive to transit use, a shortfall given that walkability in areas adjacent to transit stations is a major foundational outcome of TOD. (Atkinson-Palombo & Kuby, 2011; Cervero & Kockelman, 1997)

Recent studies suggest that in many cases, the preservation of the automobile in transit corridors has created what many look to as Transit Adjacent Development (TAD) that identify transit modes as no more than an option of travel in an auto-oriented street network known as joint development (Renne, 2009). This goes against findings brought up earlier that TOD aims to produce walk-able environments that allow for feasible transit use from mainly walk and riders. To counter the potential for TAD, one study found that mixed-use suburban centers that have been successful in attaining high transit-use, are ones where walking is feasible given the dense mixed-use environment, which reduces long trips and thus discourages auto-use (Filion, 2001). If a station has low or no park and ride spots with high ridership, one hypothesis is that a majority of transit users are not driving to that station. This means they are likely finding walking to other parts of the corridor at their origin and destination stations as an accessible means assuming the station's adjacent built environment composition is homogenous to a degree. Given this literature, it is important to gather further information about the existing relationship between the built environment and ridership of a station area.

Expanding the relationship between the built environment and ridership may best come from understanding the demand profile of riders that are attracted to LRT systems in various typologies. In 2004, a re-attempt of the P&B analysis mentioned earlier that predicted LRT ridership was conducted by utilizing a multi-regression analysis from data on nine different rail systems comprising of 268 stations using their measured ridership for all stations as the dependent variable. (*referred to as Kuby Model in this paper*) The revised methodology comprised of 17 similar and different possible factors used in the P&B analysis that prior research found to be significant towards ridership, including a CBD factor mentioned earlier to define what constituted as a downtown urban station vs. suburban station. The results were able to quantify to what extent certain factors encouraged and discouraged ridership by comparing the coefficients for each variable. Kuby et al used data on traffic generation, intermodal connections, citywide variables, network structure, and socioeconomic data. The model was statistically significant, making it a useful baseline analysis for future research towards the prediction of ridership for any LRT system.

One limitation of the model developed by Kuby et al is its limited inclusion of variables that makes the CBD factor subjective when defining urban vs. suburban built environments, although the models did incorporate a walking buffer to factor walk-ability within these corridors. Including in the model a greater range of variables that describe the physical built environment may provide additional insights into factors that shape ridership. A quantitative model that utilizes a typology analysis can show how variability in the built environment affects ridership in contrast with other variables by measuring to what extent parameters of human design vs. demand explain ridership variance within a system.

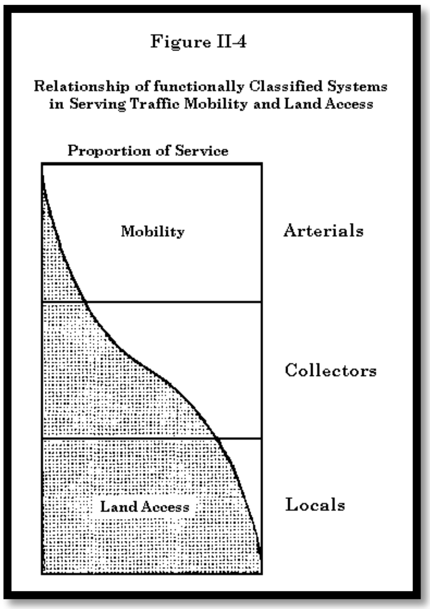

Figure Two: Functional classification of street networks (Federal Highway Administration, 1989)

Roadway Classification and Design

As previously noted, the degree of pedestrian friendliness is a primary indicator of TOD success by promoting walk and ride users. The geometric street design in this case is a critical feature of the built environment, known to influence pedestrian feasibility and development (Garrick & Marshall, 2009). The Federal Highway Administration (FHWA) identifies streets within a network through functional classification, recognizing in its definition of function that designated local or residential roads provide greater multi-modal accessibility by minimizing auto speed and capacity through safe design standards; prioritizing pedestrian behavior within its geometric design (Federal Highway Administration, 2013). In contrast, a hypothesis is that arterials that comprise mainly of limited access freeways and U.S. interstates would not produce a pedestrian friendly environment, given the limited connectivity and division of a corridor because of the physical impedance in width and safety standards designed without consideration for pedestrian use.

Our hypothesis extends to suggest that freeways and interstates affect the walkability of a station area not just because of their size, but more importantly their branching effect as illustrated by the Hierarchical Network established by the FHWA. (Federal Highway Administration, 1989) Functional classification defines arterials as thoroughfares exclusively designed towards safe and high-speed mobility of vehicles with limited accessibility, thus they have limited access to neighborhood street networks, and would be the most commonly used roads within a community requiring a higher auto capacity as suggested by the 2010 Highway Capacity Manual. (Transportation Research Board, 2010). Hierarchical network suggests that in order to support the volume produced from those who enter and exit from freeway interchanges, the capacity of nearby roads must support the volume that is loaded on and off from the Interstate to prevent congestion, measured by FHWA though a metric called Level of Service (LOS). When it comes to improving the LOS of these feeder areas, a design towards increased speed and capacity of automobiles is a primary solution that compromises accessibility and safety of pedestrian behavior, which local newspapers in Denver and Seattle found to be the case for their LRT systems that run adjacent to Interstate developments (Freemark, 2010; Moler, 2001).

The LOS parameter has long dominated the focus of network design, as a low score would point to a necessity to improve either speed or capacity of a corridor. Some of the varying solutions highlighted in the AASHTO report *A Policy on Geometric Design of Highways and Streets* include higher number of lanes, 12-foot minimum lane width, speed limits in excess of 50 miles per hour, limited pedestrian facilities, and intersection traffic control (American Association of State Highway Transportation Officials, 2001). Walkable streets on the other hand fall under design standards highlighted in the Institute of Transportation Engineers report called *Designing Walkable Urban Thoroughfares,* focusing on elements such as minimizing number of lanes, lane widths, and speed limits, while containing sufficient pedestrian facilities such as wide sidewalks, benches, on street parking, and bike-lanes (Institute of Transportation Engineers, 2010). We expect that station areas would tend to be TOD compatible from an environment of roadways that best reflect design standards from the latter as opposed to the former.

Scope of Work: City of Denver and RTD Light Rail

The city of Denver is the most compelling site to look at as the city itself has experienced rapid changes in population growth and environmental improvements over the last few decades. Its light rail system began operations in 1994, advocated for its ability to combat the reduction of air pollutants and promote sustainable growth to achieve measurable results in reducing GHG's and VMT's across the region. The region itself has faced huge population expansion that led to the opening of the Southeast Corridor consisting of 13 new stations all placed adjacent to a freeway.

The above literature compiled together helps structure a question of whether all station areas along U.S. Interstates are TOD compatible within the recognized successful framework established, and if they can produce ridership on the system that is a result of place-making aligned with TOD outcomes. TOD promotes walkable place with increased accessibility to transit and through reduced auto use, however evidence suggests street networks adjacent to interstates and freeways preserve auto mobility while providing poor pedestrian accessibility. Using the established relationships between transportation and land use up to this point, our hypothesis is that LRT station areas near Interstates are non-TOD compatible by lacking walk-able environments that attribute to higher ridership levels. A loosely based methodology replicating the Advanced TOD typology analysis will identify built environments, and a multivariate regression analysis will quantify how unique factors attribute overall ridership levels, to derive conclusions based from this section.

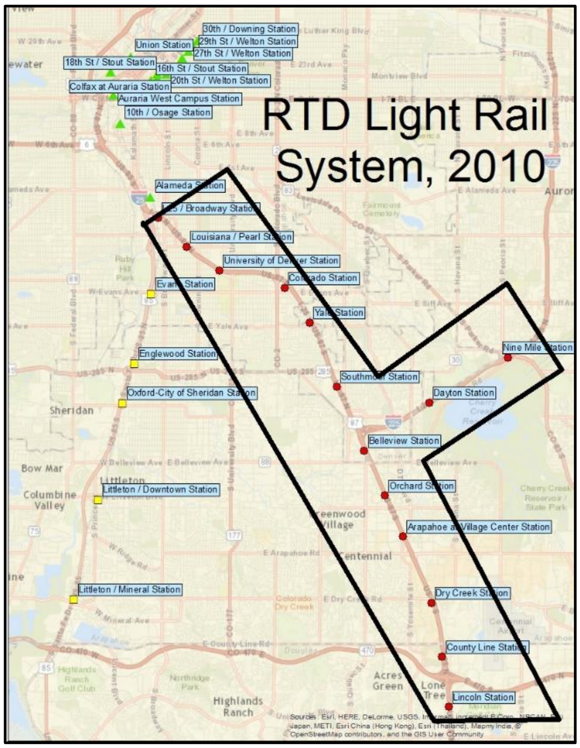

Figure Three: Map of RTD Light Rail System. Southeast Corridor is enclosed as shown along Interstate 25 and 225.

DESCRIPTION OF STUDY AREA

For this analysis, we will use the Denver, Colorado metropolitan area as a case study, given the light rail system's maturity within the city limits as well as the huge growth the region has experienced within the last few decades. According to the U.S. Census, Denver, Colorado is the 20th largest city in the United States, which includes nine counties in the metropolitan area as defined by DRCOG. The major freeways in Denver are comprised of Interstate 70 going west to east passing just north of the city boundary, and Interstate 25 going north to south passing just to the west of the city boundary. Other major routes include Interstate 225 as a partial beltway on the southeast side of the city in Aurora, as well as U.S. Route 6 that goes east to west through the Denver Metropolitan area. Amongst the major cities recognized as part of the Denver Metropolitan area, include Boulder to the northwest, Centennial and Littleton to the South, and Aurora to the east.

The RTD Light Rail System as shown in Figure three has been in place since 1994, with a series of city stops from as far north as 30th and Downing, to the 16th street mall stations and the Pepsi Center and Invesco Field sporting facilities. The system also connects to Union Station as a terminal stop where Amtrak formally made stops, and follows south to 10th and Osage, Alameda, and I-25 and Broadway stations. In the CBD including the Welton St, 16th and 18th street, the Convention Center and Auraria stops, the LRT is a shared rail system within the road. The rest of the system includes the two southern lines designed like a commuter rail with a travel speed of around 50 mph with a right of way rail corridor. The initial line installed now referred to as the Southwest Line, follows parallel along a freight route, going into the villages of Englewood, Evans, and the city of Sheridan. The line ends in the city of Littleton, stopping at the downtown village before ending at Littleton Mineral, a terminal station area.

In 2006, the T-REX program created an extension to the light rail system now referred to as the Southeast corridor, branching off from the original southwest line right after the I-25 Broadway station. The majority of the southeast corridor runs parallel along the southbound side of Interstate 25, passing the stations of Louisiana-Pearl, Yale, Colorado, University of Denver, and Southmoor. After Southmoor, another fork designed where the I-225 interchange begins off Interstate 25, is the light rail's H-line that goes to Dayton before ending at Nine-Mile Station. The remainder of the southeast corridor includes Belleview, Orchard, Arapahoe at Center Village, Dry Creek, County Line, and the terminal station of Lincoln.

DATA COLLECTION

Overview

The data used in this analysis were the most detailed and up to date information that was available in the Denver region. The time-range of the data collected varies from 2000 to 2011, and may not fully reflect the system in its entirety. All data compiled in this analysis were within a ½-mile Euclidian buffer of a Light Rail station, as a standard for the maximum distance people are usually willing to walk to a station as mentioned earlier. *(All Raw Data are in Appendix A)* In cases where there was overlap in these station areas, data collected were for the entire Euclidian buffer and ridership was adjusted using linear interpolation with the assumption that a rider could feasibly use another station if the station they currently use did not exist but was within a half mile of another station. The process includes a collection of 15 built

Built Environment Variables	Regression Variables	Dependent Variable
Land Use (Diversity)	**Typology Variables**	**Ridership**
Residential Land Use (Acres)	*Derived from Built Environment Variables	Normal Ridership
Retail Land Use (Acres)		Adjusted Ridership
Non-Retail Land Use (Acres)	**Traffic Generation**	
Industrial Land Use (Acres)	Total Population in Station Area	
TOD Land Use (Acres)	Total Retail Jobs in Station Area	
Recreation Land Use (Acres)	Total Non-Retail Jobs in Station Area	
Parking Land Use (Acres)	Total Public Jobs in Station Area	
Right of Way Land Use (Acres)	Total Number of College Enrollments in Station Area	
Vacant Land Use (Acres)		
Public Land Use (Acres)	**Intermodal Access Variables**	
	Number of Park and Ride Spots at Station	
Street Network (Design)	Number of Bus Connections at Station	
Link to Node Ratio	Freeway Corridor Binary Variable	
Intersection Density (Nodes / Square Mile)	Walk Score	
Development (Density)	**Transit Route Structure**	
Households / Residential Acre	Terminal Station (Binary)	
Retail Jobs / Acre	Designated Transfer Station (Binary)	
Non-Retail Jobs / Acre	Centrality (Normalized Accessibility)	
	Socioeconomic Variables	
	% Of Units in Station Area that are Rented	
	Median Household Income of Station Area	

*All Data Collected within a 1/2 mile Euclidean Distance of Station

Figure Four: the three categories of variables used in the typology and regression analysis

environment variables for the station typology, 14 regression variables for the multiple regression analysis and one dependent variable for the regression analysis that comprise of data gathered from multiple sources. Figure four explains the data, defined into three categories:

Built Environment Variables

The first part of the analysis as mentioned was to define the built environments that reflect the three main characteristics to support what creates a pedestrian friendly TOD in accordance with the standardized three D's of a TOD Framework (Dittmar & Ohland, 2004). Although some research has utilized other grouping classifications that include as much as five or six variable categories, the three D's is the most appropriate categories for the type of data collected and number of variables to be grouped in this analysis. A collection of 15 variables mirror these standards that help reflect the built environment that is able to measure mixed land use, density, and pedestrian friendly street network.

The land use data classified into several categories came from the three counties that have stations. The land use types include vacant/open space, residential, retail, office *(non-retail)*, industrial/agricultural, parking, public facilities, TOD designated land use, and right of way land use for road and rail lines. Parcel maps on the three county government websites GIS database *(Denver, Arapahoe, and Douglas)* helped to collect land use data. Parcel data for Denver and Arapahoe counties aggregated a land use map for the entire region in ArcGIS, along with Douglas counties regular land use map since they did not have parcel information available. Using the three data maps, a set of land use types defined the land use into a set of several land use classifications.

Development density, interpreted as building density, looks at the number of households, retail, and non-retail companies and dividing by the square acreage of the residential, retail, and non-retail land use respectively. Finally, the street network design includes intersection density *(number of intersections per square mile)* and link to node ratios of the station areas *(ratio of street segments to intersections within a defined area)*; two metrics that when found to be at high levels identify pedestrian friendly street networks (Garrick & Marshall, 2009). LOS data mentioned earlier is not a metric recorded on a national or state level and would be burdensome to collect for the study area, thus excluded from this analysis.

Regression Variables

The output from the typology analysis expects to produce a set number of typologies that will become independent variables in a regression analysis that is similar to the one performed by Kuby. These variables will be a binary set to indicate which stations of the system fit into each typology. Kuby's original analysis contained five categories that tested 17 different variables expected to impact ridership. We will exclude variables measured per transit region since our analysis only focuses on a single transit system in one region, as opposed to nine from Kuby's model; this comes to 14 variables in total collected for four different categories for this analysis, in addition to the typology variables.

Traffic Generation

1) **Retail Employment** – This counts the total number of retail based jobs whose main offices are located within the Euclidian buffer of the system. Kuby hypothesized employment to be the most important factor in ridership levels. These data came from the Colorado Department of Labor, containing a dataset full of addresses that were geocoded

to form a point shapefile in ArcGIS for the year 2010. The extraction of retail employment counts for a light rail station buffer come from a GIS layer, by aggregating parcel records within a half mile buffer of the station into land use types utilizing North American Industry Classification System (NAICS) codes and extracting those records that best reflect retail oriented industry. Employment count summations from those retail oriented records determine total station employment.

2) **Non-Retail Employment –** Same as Retail Employment except filters only jobs that are determined to be non-retail employment jobs.

3) **Public Sector Employment –** Same as Retail Employment except filters only jobs that are determined to be public sector employment jobs. *(Mainly Education or Government Jobs)*

4) **Population** – This counts the total number of people who live in housing within a half-mile Euclidian buffer of the system. Expectations are that higher population of an area draws higher ridership. Block data for 2010 on the census website determined most accurate population counts. The data joined to a block shapefile to create a population layer for Denver, and then used spatial analysis to determine what percentage of the block was within the Euclidian buffer. The final population count is determined by applying this percentage to the total population count with all the adjusted block populations within the Euclidian buffer that sum together.

5) **College Enrollments** – Educational trips on average make up 14% of transit trips (Pickrell, 1992). This counts the total number of enrollments at colleges that are within the Euclidian Buffer. Google Imagery determined college enrollment by identifying all

the colleges that existed within Euclidian station buffers, and accessing website data to find total students that attended all secondary schools.

Intermodal Access Variables

1) **Park and Ride Spots** – RTD had GIS data that indicated coordinate locations of light rail stations as well as the total number of park and ride spots for each station. Kuby's regression model found that .774 park and ride spots generate one daily boarding or 1000 daily boarding's for every 774 park and ride spots.
2) **Bus Connections** – The RTD website has data that shows how many total bus routes stop at each light rail station. More bus connections suggest higher regional connectivity and likely higher ridership.
3) **Freeway Variable -** The regression analysis also includes a freeway variable that is a dummy variable to identify if whether a freeway runs parallel with the Light Rail system. For this analysis, freeway variables were only applicable to U.S. Interstates, as the functional classification system identified that there are divided highways that appear similar in geometric design to a U.S. Interstate but classified as a separate arterial type.
4) **Walk Score –** A parameter used and validated in prior literature as a method to dictate walk-ability of a neighborhood. It scores walkability by examining the accessibility to retail, education, food, recreation, and entertainment within a one-mile radius with a distance decay function. The scores range from 0-100, with 100 being the completely walkable and zero being completely auto-dependent. If walk score is significant in the model, it may quantitatively indicate which stations are more conducive to walk and ride ridership.

Score	100-90	70-89	50-69	25-49	0-24
Description	Walker's Paradise	Very Walkable	Somewhat Walkable	Car-Dependent	Car-Dependent

Figure Five: Walk Score Ratings and Descriptions. (Walk Score, 2010)

Rail Route Structure Variables

1) **Terminal Station** – To designate an end of system station, a dummy variable for terminals produces a one to factor additional ridership, hypothesized by Kuby to be the case at most terminal stations.
2) **Transfer Station** – Ideally, many stations on the Denver line are transfer stations, as there are five routes; however, Kuby suggests restriction to designated transfer stations as the dummy variable. The Denver system in this case has four designated transfer stations.
3) **Centrality** – Kuby describes centrality as the relative accessibility of each station to all other stations, measuring the average travel time one station has to all other stations. This number divided by the highest average travel time for the entire system, creates a value ranging from zero to one, one meaning the station has the worst centrality and longest travel time to the central part of the system. Stations near the middle of the system will typically have the lowest centrality value. Large variance in values can suggest a system stretched out too much, possibly indicating design reflecting a commuter rail system.

Socioeconomic Variables

1) **Percent Renters** – Given the number of households in the station corridor occupied, this extracts the percentage of tenants renting their household. Census data calculated this at the block group level for 2010, and uses spatial analysis in Arc Toolbox in ArcGIS to

calculate the percentage of renters in the Euclidian buffer. Kuby's model found that in a corridor completely occupied by renters, the station would generate 624 daily boarding's on average.

2) **Median Income** – Given the number of households in the station corridor, this is the median value of the household income for the corridor. This was calculated using the same method as Percent Renters, and create an adjusted mean of the median incomes.

Dependent Variable

Adjusted Ridership - The dependent variable for this analysis is ridership for each light rail station, measuring total daily weekday ridership on average for August of 2011. This data is available at the RTD Light Rail website. Ridership adjusted for overlap in Euclidian station corridors, by performing linear interpolation to add ridership on the presumption that if the adjacent station did not exist, a user would walk to the associated station to ride if still within a ½ mile. Ridership is one of the most simplistic indicators of system wide VMT reduction as the majority of people who board rail are replacing or shortening auto trips with LRT to reach their destination.

$$AR_j = \sum R_i * O_{ij}$$

Where: $AR_j = Adjusted\ Ridership\ of\ Station\ j,$

$$i = Station\ i,$$

$$O_{ij} = Percentage\ of\ Station\ i\ Euclidian\ Corridor\ that\ intersects\ Euclidian\ corridor\ of\ Station\ j,$$

$$*\ when\ i\ and\ j\ refer\ to\ same\ station, Oij\ will\ equal\ 1\ reflecting\ the\ actual\ ridership\ of\ the\ station\ j$$

METHODOLOGY

Typology Analysis

The software used for the typology and regression analysis is an International Business Machines Corporation (IBM) product called Statistical Package for the Social Sciences (SPSS) used for a wide variety of statistical analyses including cluster analysis and multi-regression. All data collected for each station in the previous section are copied and pasted from an excel spreadsheet into a table on the user interface which is then saved by the program that can be called to run any series of statistical tests.

The objective of the typology analysis is to establish a set of station typologies for the light rail system that are defined by a set of independent variables that define each station from a built environment perspective measuring levels of mixed land use, building density, and pedestrian friendly street networks. A factor analysis and cluster analysis performed a statistical method used to best categorize a set of observations into smaller classifications for comparison to produce the necessary results. Factor analysis performed prior to the cluster analysis is useful when dealing with a large number of independent variables that are considered in a cluster analysis, to reduce multicollinearity in the variables by creating an uncorrelated set of factor variables (Lawley & Maxwell, 1971).

When running factor analysis, factoring requires selecting which variables from the data spreadsheet to consider. This analysis involves in this case selecting 15 total variables including the 10 land use types, residential, retail, and non-retail density, and intersection density and link to node ratio. When running factor analysis, there are several possible methods to consider, which are rotations of the correlation matrix derived from different statistical algorithms. The possible rotations considered are as follows (Abdi, 2003):

1) ***Principal (Un-Rotated)*** *– Maximizes the variance accounted for by the first and subsequent factors, forcing factors to be orthogonal*

2) ***Varimax*** *– Maximizes the factor axes to maximize the variance of the squared loadings of a factor on all the variables in the factor matrix, differentiating the original variables by extracted factor. Most common rotation option*

3) ***Quartimax*** *– Minimizes number of factors needed to explain each variable. The rotation often generates a general factor on which most variables are loaded to a high or medium degree.*

4) ***Equimax*** *– a compromise between the Varimax and Quartimax*

Loadings (%)	Principal Analysis					Quartimax Rotation					Equimax Rotation				
	Component					Component					Component				
Factor Variables	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Residential Land Use (Acres)	8	-91	16	-30	-12	9	-94	27	7	7	-1	7	-93	-28	15
Retail Land Use (Acres)	-24	13	-38	73	-14	-16	15	-81	6	-24	-13	-3	51	-54	-44
Non-Retail Land Use (Acres)	-8	50	-59	-1	-32	-11	44	-47	10	53	-11	-14	68	-27	38
Industrial Land Use (Acres)	-15	-4	43	65	40	-7	7	-7	2	-88	3	9	-1	15	-87
TOD Land Use (Acres)	78	26	-14	9	30	81	35	3	14	-2	82	19	26	14	8
Recreation Land Use (Acres)	-17	33	60	-20	41	-21	36	64	4	-35	-11	-6	-5	80	-22
Parking Land Use (Acres)	18	78	39	-15	8	7	77	38	27	-1	4	25	46	73	9
Right of Way Land Use (Acres)	82	-22	-13	28	3	86	-15	-20	4	-9	75	40	-6	-29	-1
Vacant Land Use (Acres)	-59	6	-41	-43	32	-54	4	15	-64	29	-25	84	3	8	19
Public Land Use (Acres)	30	16	60	-6	-59	13	7	20	87	8	-22	82	-5	25	20
Link to Node Ratio	82	1	18	17	-3	79	6	4	30	-11	62	59	-2	4	3
Intersection Density	87	-34	3	4	-2	88	-29	5	15	1	72	48	-30	-17	15
Households / Residential Acre	69	56	-24	-11	3	64	57	0	-2	33	60	20	51	18	40
Retail Jobs / Acre	69	16	-4	-31	-15	62	14	19	18	40	47	35	5	13	52
Non-Retail Jobs / Acre	71	-26	-33	-17	42	79	-17	14	-45	11	88	-12	-22	-10	21
Sum of Abs Values of Loadings	**1083**					**1147**					**1112**				
Number of Iterations	*No Iterations for Principal Analysis*					*Converges in 19 Iterations*					*Converges in 8 Iterations*				

Figure Six: Factor Analysis Rotation Charts. *See Appendix B for Full Results*

The other two possible rotations are a Direct Oblimin and Promax rotation. However, these non-orthogonal solutions make some variables irrelevant and not recommended for use in this analysis.

Choosing the best rotation involves looking at the factor matrix, and analyzing the highest loadings *(positive and negative)* on each of the factors for each independent variable a shown in Figure six. The higher the degrees on the loadings, the more uncorrelated the factors become. These factors can also suggest how different cluster groups will form based on which high loadings are within each factor variable.

In this analysis, we found the absolute value of the highest loading for each variable and took the sum of these values using the rotation with highest sum as the best statistical fit for the factor analysis. Once the best rotation is determined, the program needs to save variables. This will output on the data spreadsheet a new set of columns after all the independent variables, which are the factor variables that are required for the cluster analysis. The cluster analysis performs using only the saved factor variables from the factor analysis and using a Hierarchical method, based on the idea of objects relating to near-by objects more than objects farther away. This uses a distance function called linkages to form clusters, by constantly grouping observations together into like sets until all the observations said to be in one cluster alike. This uses a squared-linked distance to categorize stations. Clustering using Ward's method occurs as well, which uses a sum of squares criteria to maximize differences and minimize within-group differences (Atkinson-Palombo & Kuby, 2011). K-means cluster also considers clusters represented by a central vector and creates an optimization problem by finding the k cluster centers and assigning the observations to the nearest cluster center for minimization of squared distances. Because the number of clusters needs specification in advance, excluding this process was allowable.

Using the Hierarchical Cluster analysis method has the ability to produce a dendrogram that illustrates the clustering of stations into groups over linkage distance. Figure seven shows how this process works, which involves making an imaginary cut along the dendrogram and choosing three to five clusters to produce best-fit results. When it is determining how many clusters necessary, group numbers in a separate column on the data spreadsheet must manually identify the stations. The dendrogram will identify stations with a group number that matches the row number in the spreadsheet.

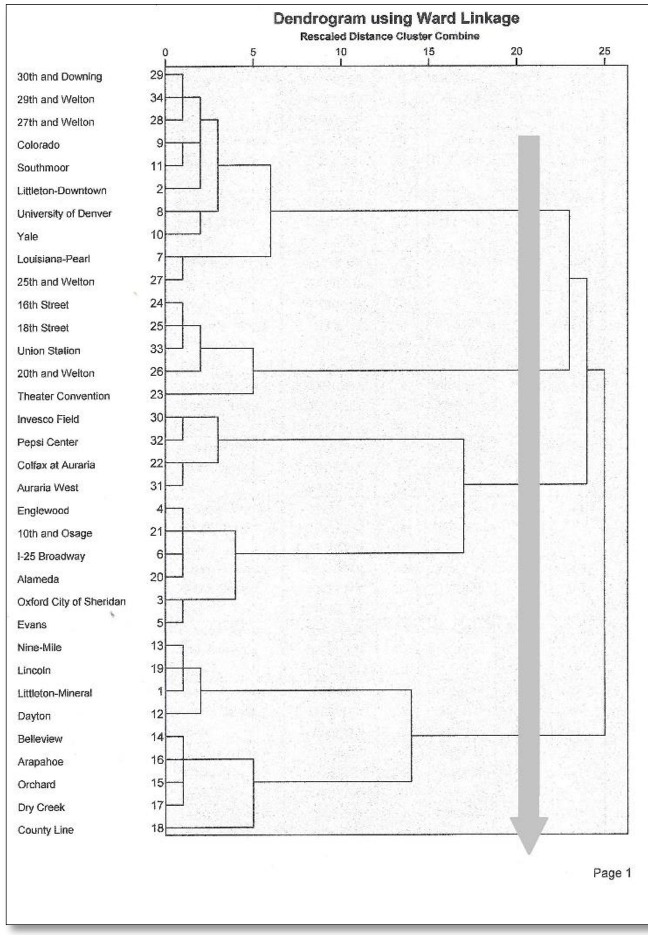

Figure Seven: Dendrogram for Visual Illustration of a Cluster Analysis - Using Ward's Method. *See Appendix D.*

It must be determined how the final output is significant statistically given the dendrogram results. ANOVA tests conducted on the cluster results look at all the built environment variables, regression variables, and ridership variable collected, and analyze their significance by group number. Figure eight shows a sample of the SPSS output, which includes the significance factor. *(See Appendix E for full results)* Using a 95% confidence interval, values of this factor that are less than .05 are variables that are significant by group and used to explain variances for different typologies. Ridership significance by group is important to identify if there is a significant relationship between ridership and the built environment. Descriptive statistics are also produced which identify averages by group for each independent variable, including mean, standard deviation, minimum/maximum, and upper and lower bounds. The mean values by group describe typologies using only the built environment variables found to be significant by group in the ANOVA results.

ANOVA						
Variable	**Type**	**Sum of Squares**	**df**	**Mean Square**	**F-Test**	**Significant**
Residential Land Use (Acres)	Between Groups	141758	3	47253	27.700	0.000
	Within Groups	51182	30	1706		
	Total	192940	33			
Retail Land Use (Acres)	Between Groups	5141	3	1714	1.509	0.232
	Within Groups	34069	30	1136		
	Total	39209	33			
Non Retail Land Use (Acres)	Between Groups	47985	3	15995	8.302	0.000
	Within Groups	57801	30	1927		
	Total	105787	33			
Parking Land Use (Acres)	Between Groups	16293	3	5431	5.310	0.005
	Within Groups	30684	30	1023		
	Total	46977	33			
Recreation Land Use (Acres)	Between Groups	3924	3	1308	2.810	0.056
	Within Groups	13963	30	465		
	Total	17887	33			
Ridership	Between Groups	1571375432	3	523791810	16.547	0.000
	Within Groups	949619182	30	31653973		
	Total	2520994614	33			

Figure Eight: Sample One Way ANOVA results. *See Appendix E for Full Table.*
*Variable Not Significant if >.05

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Residential Land Use (Acres)	1	10	194	49	16	159	229	126	302
	2	5	26	13	6	10	42	13	48
	3	10	58	38	12	31	85	0	127
	4	9	69	45	15	34	103	5	145
	Total	*34*	*96*	*76*	*13*	*70*	*123*	*0*	*302*
Retail Land Use (Acres)	1	10	19	16	5	8	30	1	54
	2	5	32	10	4	20	45	16	41
	3	10	41	30	10	19	63	16	98
	4	9	51	54	18	9	92	0	175
	Total	*34*	*36*	*34*	*6*	*24*	*48*	*0*	*175*
Non Retail Land Use (Acres)	1	10	12	14	4	3	22	3	47
	2	5	85	24	11	55	115	46	109
	3	10	15	13	4	6	24	0	47
	4	9	93	81	27	31	155	0	247
	Total	*34*	*45*	*57*	*10*	*25*	*65*	*0*	*247*

Figure Nine: Sample of Descriptive Statistics produced during a One-Way ANOVA. *See Appendix E for full table.*

The typology labels are user-defined in ways that are clear to interpret and can help clearly distinguish the group types. Development density level, zoning compositions, street network types, and stations adjacent to freeways, are features of the build environment commented on in the analysis to determine these labels. Mean values quantify the presence of such features as shown in Figure nine, defined as high, average, or low values. Using all the information gathered about the comments, a general typology label forms to associate with what type of classification is appropriate; illustrated through a typology rubric form created that can be seen in Appendix C.

Given the hypothesis that different ridership levels of the group reflect the typology of the built environment, each typology should note and rank the average ridership of each group. Typologies that contain a majority of the freeway stations and what those stations ridership levels are, is important to help establish important relationships between the freeway and built environment. More importantly, all the variables collected for the regression analysis should also be analyzed by cluster as they may be strong predicators to establish uniqueness amongst the groups that can be reflected in the regression model. The main output from the overall analysis is establishing if there is a significant relationship between the built environment and ridership in the ANOVA results in figure 10, to warrant a further validation of this significance quantitatively.

ANOVA

Adjusted Ridership per Day

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1571375432	3	523791810.7	16.547	.000
Within Groups	949619182.3	30	31653972.74		
Total	2520994614	33			

Figure 10: ANOVA for Adjusted Ridership per Day. *See Appendix E for Descriptive Statistics*

Regression Analysis

The ANOVA results from a typology analysis showing significance between the built environment and ridership can further validate quantitatively through a regression model, what aspects of station areas related to TOD outcomes can attribute overall ridership levels. Existing research found that Kuby's multiple regression model is the most effective method in predicting light rail ridership. Predicting factors in a multiple regression analysis can conclude through statistical processes the extent that certain factors of a station environment influence ridership. Kuby tested 17 hypothesized variables researched to have an impact on light rail boarding's and placed them into OLS regression. Five variables were non-significant while 12 were significant.

His final model based on data for nine light rail systems produced a universal model potentially for other light rail systems, such as the Denver system.

The data for the 12 variables collected as noted in the data section for each station used Kuby's regression model for testing. Measured ridership in comparison with the actual ridership reflective of the RTD counts from August 2011, produced percent error values to determine model accuracy. In the case of significant error between the two values, Kuby's model failed to provide a best-fit approach for predicting the factors influencing ridership. The appendix has record of the errors.

We found in Kuby's model that elements for the built environment excludes some of the key TOD elements mentioned earlier. For example, Kuby used a ½-mile walking buffer that can reveal elements of the street network design, however it fails to address existing land use and density levels of areas outside the walking buffer but within a ½ mile Euclidian. This research uses a Euclidian buffer to keep each station's study area consistent, and better identify incompatibilities of a TOD built environment by assessing street network design at the same scale for each station. This research also incorporates the typology analysis clusters classifications of built environments, which allows use of a regression model that is similar to Kuby's without adding numerous separate variables to the regression analysis already used in the typology analysis.

After the typology analysis is complete, a regression analysis must identify what variables play the largest role in ridership without correlating to an entire set of stations. For each station, a Pearson correlation matrix *(See Appendix F)* compared the regression variables with adjusted ridership, selecting variables that were most correlated based on the values in the table and significant at the .05 confidence level using a 2-tailed test. The Denver model excluded a few variables used in Kuby's model, as they were either non-existent or constant amongst the entire system. The model also excluded airport and border variables since LRT does not connect to either feature, as well as degree-days plus employee coverage since they were constants amongst the system. College Enrollments, originally removed from Kuby's analysis, needed reinstatement for the equation since the research suggests education influences ridership. The freeway variable as mentioned earlier is also used as a dummy variable for this analysis, to analyze if the model can predict the freeway as a significant factor for ridership on the entire transit system.

The regression analysis involves placing all the selected variables into the regression equation as independent variables, with ridership being the dependent variable. The software does not produce automatically a best-fit model, as there are many statistical parameters to consider. The main model parameters to focus on are R, R2, adjusted R2, standard error of the model, and significance of each variable. It is also important to exclude the value of the constant variable, under the assumption a station that does not provide any nonzero present of these variables should produce zero riders. ANOVA parameters to consider are F-statistics and model significance, while the main parameter to focus on for the coefficients is there overall significance in the model. Significant values should all be under .05 to fit in place with a 95% confidence interval, while all other parameters should be as high as possible. For this case, we use a stepwise backwards regression model that will take out the least significant variable in each step, until the model produces an equation where all variables are significant at the 95% confidence interval. R2 values should be at least .6 with an adjusted R2 of at least 0.5. Once a model run occurs, the output produces a set of unstandardized coefficients. *(See Appendix F)* The coefficients produced interpret different metric types such as a binary, percentage, or numerical, based on the range of values that the independent variables contain. Figure 11 can explain how to interpret these variables.

Variable Type	**Description**	**Variables**
Binary Variables – 1 or 0 entries only	Represents number of estimated riders attracted or un-attracted to a station based on the existence of such feature	Terminal, Transfer, Freeway, Typology Variables
Percentage Variables – 0 to 1 only (Decimal)	Number of riders attracted or un-attracted to the system if the feature is absolute (100%), Linear relation between feature and ridership factored from variable	Centrality, % Renters
Numerical Variables – Any Real Number >0	Either a percentage or a multiplier of observed value in station corridor that translate to number of attracted or un-attracted riders to a system per unit of the feature	Population, All Employment Variables, Park and Ride, Bus, Median Income

Figure 11: Interpreting Coefficient's in Multi-Regression Analysis

The final step is to run the regression results produced from the model and compare ridership explained by the model with the RTD measured ridership. Our reasoning behind running this model is to produce significantly less residual errors than the Kuby model runs. While expected that some stations may not fit well depending on the standard error of the final model, there should be overall improvements from the Kuby model.

RESULTS

References for all data and results from this analysis are located in the appendix of this paper, starting with the factor matrix results for the four possible rotations. Looking at the total values of all loadings, the Quartimax rotation was the best-produced rotation. The analysis found that there were no substantial differences between the Principal analysis, Quartimax rotation, and Equifax rotation, with the Verimax rotation voided after 25 rotations.

Using the Quartimax rotation to produce factor variables, the hierarchical cluster analysis performed divided stations into four clusters, which produced clusters made up of ten, five, ten, and nine stations for the four clusters. The ANOVA tests in Appendix E found that all the variables of the built environment were significant in the analysis with the exception of retail and recreational land uses. Ridership and Adjusted Ridership were significant between the groups at a level of .000 respectively.

Typology explanations include the details of the descriptive statistics by mean values, as well as the group average of station ridership ranking and the typology formed. The four typologies formed were Variable Density Business Centers, High Density Mixed Use Downtown, Low Density Retail and Entertainment Centers, and Low Density Commercial Centers.

Variable Density Suburban Centers – Ridership Rank: 3rd -

(*2,776 Daily Average Riders; 4,362 Adjusted*) – (10 Stations: Five Adjacent to Freeway)

Ten of the 36 stations fit into this typology, all of which strongly reflect the standard three D's of TOD characteristics despite lower ridership. These stations saw a lot of land use that was dedicated to residential land use but had the lowest amount of households per residential acre at 14.61 Households/Acre. Densities were higher in neighborhoods where businesses were prominent, showing a land use typology that has a proper heterogeneous mix of land use. The design of the built environment is conducive as there were high levels of Intersection Density and Link to Node Ratio at 142.48 (*Intersections / Square Mile*) and 1.80 respectively. These are mostly stations just outside the Central Business District with grid like networks that are pedestrian friendly with low amounts of land uses in vacancy and parking yet do not always translate to increased ridership.

<u>High Density Mixed Use Downtown</u> – Ridership Rank: 1st -

(*6,684 Daily Average Riders; 23,278 Adjusted*) – (Five Stations: None Adjacent to Freeway)

Five stations fit into this typology, where again there is a mix of land use that leaned heavily towards commercial, yet all densely developed land use types in the corridors that contained pedestrian friendly street networks. These stations had the highest density of Retail and Non-Retail Jobs per acre of all groups at 7.15 (*Companies / Acre*) and 2.01 (*Companies / Acre*) respectively. These were mostly communities that were in the CBD, suggested by the highest Intersection Density and Link to Node Ratio at 153.55 (*Intersections / Square Mile*) and 1.99 respectively of the four groups. While these stations did have the highest parking land use of the groups, it also had sufficient recreational land use as well as high TOD Mixed use, and Public Land Use, ensuring these were places where activity was the highest.

<u>Low Density Retail and Entertainment Centers</u> – Ridership Rank: 2nd -

(*5,043 Daily Average Riders; 9,716 Adjusted*) – (Ten Stations: One Adjacent to Freeway)

This group which has ten stations, reflects special event locations that don’t necessary target residential or commercial environments, but rather the sporting arena stations, the education centers, and stations along the Southwest Corridor that are neither adjacent to a freeway or in the CBD. There are low amounts of residential and non-retail land use, yet despite high retail land use, the area illustrates as a low density developed area. Intersection Density and

Link to Node Ratio were around median levels in the system at 75.25 (*Intersections / Square Mile*) and 1.69 respectively.

<u>Low Density Commercial Centers</u> – Ridership Rank: 4th -

(*2,776 Daily Average Riders; 2,776 Adjusted*) – (Nine Stations: Eight Adjacent to Freeway)

These are all stations that are furthest away from the CBD, have low public parking land use (*although it is known that these stations all have park and ride*), and be comprised of mostly commercial land use, all of which is low density. From a street network design, these stations have the lowest intersection density and link to node ratio at 42.16 (*Intersections / Square mile*) and 1.32 respectively. There are also high levels of land that are undeveloped.

The ANOVA test and analysis of descriptive statistics showed a lot of clustering of key regression variables amongst the four groups. Of the 14 stations adjacent to freeways, five were in group one, one in group three, and eight in group four, but more notably was that the eight freeway stations made up a group of nine stations, showing the presence of freeway to be extremely significant among this group.

Kuby's original regression model equation expected to produce extremely useful results, however the degree of error produced left the model useless for the analysis. Kuby’s model required a measure of data to be within a walk-able buffer along the road network as opposed to a Euclidian buffer, so the data adjusted in all cases to reflect this. The regression analysis needed to utilize a Euclidian buffer for consistency with the typology analysis that required a Euclidian buffer for accurate spatial comparison of typologies. Out of the 34 stations, the station that produced the least error between Kuby's model estimation and the actual ridership was the Pepsi Center station at 13%. The 10th and Osage and 18th Street stations contained percent errors that were over 100% and in most cases, the measured ridership was well below the actual ridership. Therefore, evidence showed that the model needed adjustment to reflect metrics mentioned in the literature review section about Kuby's analysis regarding the exclusion of non-significant values like college enrollments as well as the lack of taking into consideration of the built environment.

The correlation matrix in figure nine showed that among all the regression variables, eight variables were correlated with the adjusted ridership variables with a 95% confidence interval which is .334 when n=34. The variables included total population, all three job categories, walk-score, percentage of renters, freeway binary variable, and centrality. The stepwise backward regression model took out all our variables except for walk score and public sector jobs. These were both more than 99.9% significant despite being the only two variables included. The model had an R=.929, R2=.863, and an adjusted R2=.855, with a standard error of 4558. ANOVA test found the model to be statistically significant (.000) with an F-test of 101.035. The coefficient values of the walk score and public jobs were 63.842 and 2.362 respectively, with t scores of 4.949 and 7.949 respectively. Thus the final linear equation to consider is:

$$Y_r = 63.842*X_{ws} + 2.3628*X_{pj}$$

Where
Y_r=*Adjusted Ridership of Station* X_{ws} = *Walk Score of Station*
X_{pj}=*Number of Public Sector Jobs within Station Buffer*

While the standard error is high, our model suggests that this is unavoidable due to a small sample size. Thus it is expected that without a collection of data amongst multiple systems, a model cannot be created that will produce a linear equation to accurately predict ridership, but rather establish a common pattern.

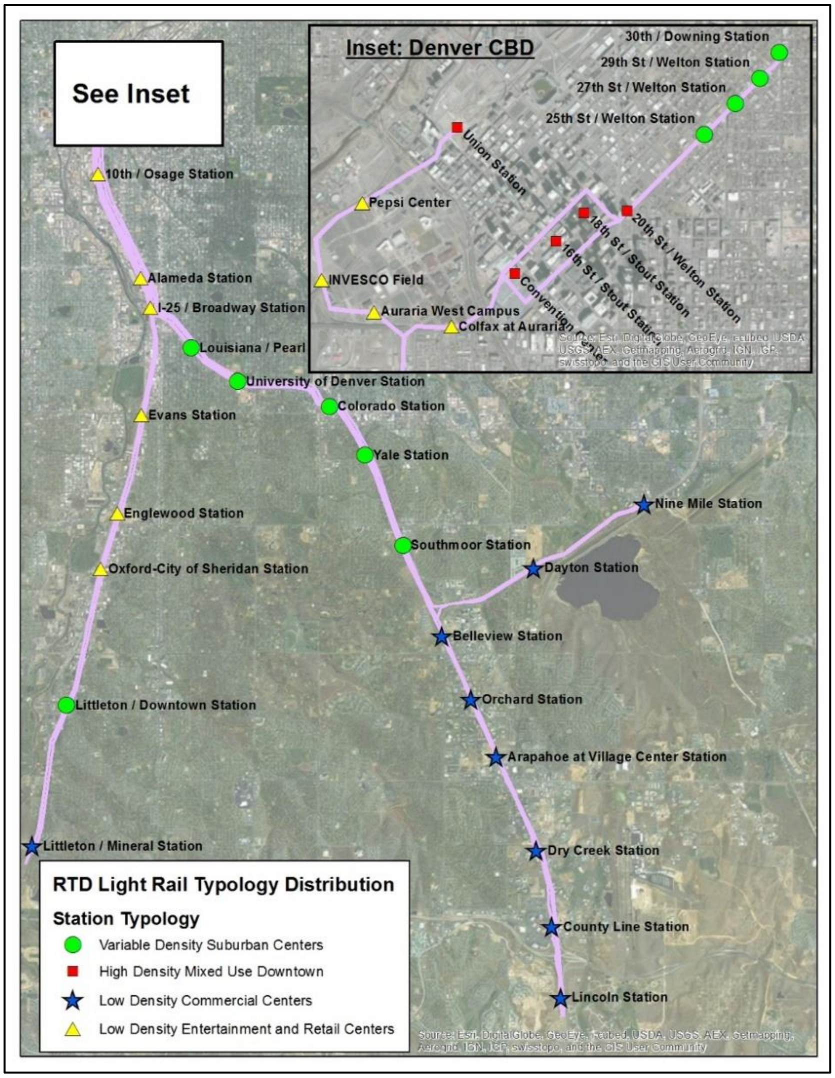

Figure 12: Spatial Breakdown of Typology Analysis

DISCUSSION OF RESULTS

Typology Analysis

The typology analysis found that 13 of the 14 stations adjacent to freeways fell into two groups, Variable Density Suburban Centers (*Group one*) and Low Density Commercial Centers (*Group four*). Many station areas within group one were somewhat TOD compatible environments as they showed to have street network designs that reflected walk-able environments. However, the land use balance was not at a desirable level indicative of being mixed, and the density levels were low for residential and slightly above system average for commercial.

The five stations with adjacent freeways in this group were Colorado, Southmoor, University of Denver, Yale, and Louisiana-Pearl. The other stations in this group were the 25th, 27th, and 29th, and Welton Street stations as well as the Littleton Downtown stations. As highlighted in the previous section, while these built environments appeared to be pedestrian friendly, ridership levels on average were on the lower end of the system. Most stations in this group had features such as dominant levels of small yard single family residential, a few public parks, schools, and small retail in a downtown setting. These stations may not quite be TOD compatible despite being pedestrian friendly, as the lack of sufficient development density and land use mix may suggest evidence that these regions are not quite self-sufficient despite being a walk-able environment.

Group four had eight stations adjacent to freeway and was a group of nine. Although this analysis excluded a freeway variable, these results proved that certain stations developed near freeways produce similar built environments. These stations produced clear evidence of a non-TOD compatible typology, as they showed street networks that were underdeveloped and presented poor connectivity that would not suggest these were walk-able streets. These built environments likely contain single-family communities with auto-centric commercial centers that would have large privately owned lots. While these stations were heavy commercial centers, they contained too much vacant/open land along with low residential and commercial density to suggest trip generation produced within these corridors is high.

These eight stations were Lincoln, County Line, Dry Creek, Arapahoe at Center Village, Orchard, Belleview, Dayton, and Nine Mile, with Littleton Mineral being the only non-freeway station. They contained a built environment that had some multi-family apartments/condos, but otherwise were dominated by box retail outlets, large parking lots, and otherwise undeveloped or open space. It was suggested earlier that these features reflect environments that are highly auto-dependent and do not promote a dense, walk-able environment. This group had the third lowest ridership out of four groups, suggesting that trip generation is not sufficient. This coupled with low representation of the Three D's provides clear results that the typology is non-TOD compatible.

The other two remaining typology groups were High Density Mixed Use Downtown (*Group two*) and Low Density Retail and Entertainment Centers (*Group three*). Group two consisted of 16th street, 18th street, Theater/Convention Center, Union Station, and 20th and Welton stations. These stations were the most TOD Compatible stations in the system, as they showed the highest levels of intersection density and link to node ratio to support a walk-able network. These stations also had the highest levels of residential and commercial density but more importantly provided a balance of land uses that best define mixed land use. Common features you would find in these environments include tall office and apartment buildings, large sidewalks, large amounts of small retail, and occasional use of public buildings and parks. There were high levels of industrial land use and parking land use, which suggests that while the Link to Node ratio is high, the

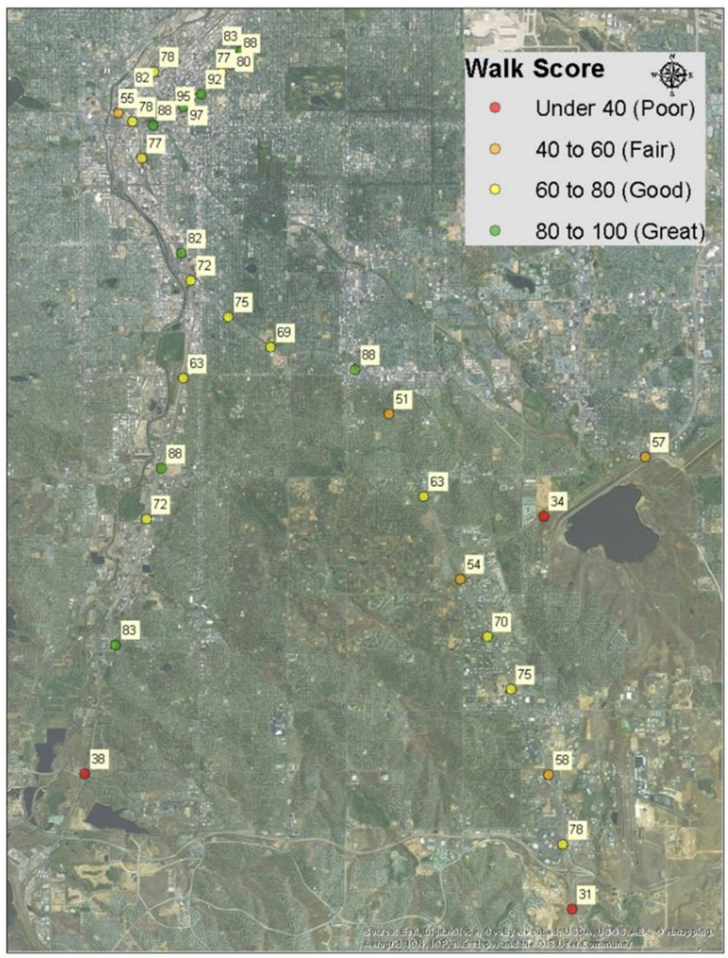

Figure 13: Walk Score of RTD Light Rail System, 2010

area likely is not pedestrian friendly or with sufficient amounts of activity, with education being a possible reason why ridership is high in these areas.

Group three consisted of 10 stations that contained the 2nd highest ridership of the four groups, yet did not show typologies that reflect TOD compatibility. These stations had about average levels of intersection density and link to node ratio that suggest these are questionable in walk-ability. While there were high levels of retail, public, and recreation land use, there were also high levels of industrial and parking land use, which do not allow a corridor to be TOD compatible if it is excessive in nature. The low density in residential and commercial activities reflect a lack in trip generation, despite the high ridership. A good portion of these stations features a special use destination with accessibility to arenas, colleges, and amusement parks, which subject stations to seasonal variability in ridership. While these stations may ultimately reduce auto oriented trips in unique circumstances, these environments TOD compatibility are questionable at best.

Regression Analysis

Our regression results showed that while our model was statistically significant, it was overall inconclusive due to the lack of a sufficient sample size that could reduce our standard error to produce accurate modeled results of variable defined ridership. Our results found however that a high walk score and the amount of job density in the public sector were the most crucial variables linked to high ridership, with walk score being a strong predictor in the walk-ability within a corridor. What these results showed was that in general walk score positively correlates with ridership numbers along with public sector jobs in schools and government buildings also encouraging use. Public Sector jobs was significant amongst the groups in the

ANOVA test and descriptive statistics, and is a good indicator that public space such as schools, parks, government entities, or public services are places that people would favor to ride transit to from a system standpoint. However, the model appeared to weigh walk score to be a more critical factor in ridership levels.

ANOVA and descriptive statistics from the typology analysis found that walk score was a significant variable amongst the groups, where it was found to be extremely high in groups one and two, yet lowest in group four. A high walk-score as mentioned earlier represents a general theory that having a variety of services within close distance of a point of interest in indicative of an environment that is likely to be pedestrian friendly, as it suggests a high density of mixed land uses. Combined with literature earlier about street network design, these high-density areas are likely to contain streets with higher connectivity as well as sidewalks and safer geometric design for non-auto users. Thus our model which was designed towards TOD compatibility supports the theory that a walk-able setting will produce overall higher levels of ridership. This was mainly evident at the downtown stations where walk scores were close to 100 and ridership was near the top of the system.

Alternatively, a lower walk score suggests that accessing most places would require doing so by automobile. Figure 13 shows that of our 14 freeway stations, none placed above a score of 90 out of 100; the range where most trips are accessible by walking, with eight stations below a value of 70; the threshold where a substantial amount of trips would require an automobile to complete (Walk Score, 2010). While this shows that not all freeway stations are auto-dependent, there is evidence of a rare occurrence to find a freeway environment that is completely pedestrian friendly, particularly within a transit corridor. The only two stations in the southeast corridor to score above 80 was I-25 Broadway (*82*) and Colorado (*88*). We find these results to produce valid evidence of a non-compatible TOD environment given the lack of density and appropriate road design within the composition of the land uses that appropriates walk-able communities.

CONCLUSIONS

Overall, our analysis found evidence that building adjacent to U.S. Interstates does not produce TOD compatible station areas given its compromise to walk-able environments, which in return does not produce an optimal reduction in VMT in these regions. The results of this study show a static time representation of two different built environments that occupy both a LRT station and an interstate highway. Our typology results showed two different built environments that exist in nature along interstate highway corridors. Our regression model showed that station areas with higher walk scores and more public spaces were more likely to be TOD compatible due to their significant link to ridership levels, which was found to generally not exist at station areas adjacent to the U.S. Interstates in Denver.

Our group one typology showed five stations along the freeway that reflected a grid like street network design with some level of mixed land use that was predominately-single family residential. However, despite a large capacity of potential pedestrians and system riders, many of these stations sustain ridership levels on lower ends, supported by walk scores that were not nearly as high as TOD compatible corridors reflect. It was also worth noting that these stations had little to no park and ride, which may shed light on the dominant role that automobiles have over pedestrians due to the hierarchical network design near freeways. Additional research may want to look at this more in detail to understand why these areas have low ridership when they appear to have TOD compatible street network designs.

Our group four typology captured eight stations adjacent to interstate highways that were more visibly non-TOD compatible. Street network designs along with low densities established these locations were underdeveloped and coincidentally were furthest away from the CBD in the system. These stations were heavy commercial centers that allowed some walk scores to be at considerably high levels, but the typology shows that these locations are box retail outlets with many parking lots.

Our typology analysis found that while group four stations exhibited less TOD compatible characteristics than group one stations, a few still manage to bring in more ridership particularly at ones with large amounts of park and ride spaces. This supports earlier literature that these stations have facilitated suburbanized development by bringing commuters into the city, thereby supporting the notion that these stations are feeder stations suggesting the RTD system to be a commuter rail system. There is reason to believe these stations adjacent to interstate highways have been able to produce high levels of ridership through the development of park and rides. This hypothesis was lightly supported by our data that showed on average, these stations within group one had much lower levels of park and ride along with lower ridership counts, as opposed to group four stations. Although our research did not find park and ride to be significant in this study, we find this to be an important question to research in further studies to better support our conclusion.

As the Denver region continues to grow, we expect there will be many challenges these freeway stations will encounter as they build out into potential TOD compatible corridors. Group one stations must encounter greater land use diversity and higher densities to allow some of these stations to become destinations along the system that allow for more potential users. Group four stations face much longer build out scenarios as many of these station corridors contained too much open space and built environments that heavily favor auto use. The existing conditions in terms of infrastructure and street network raise concern if these corridors can ever develop to a sufficient level of building density and grid like street network that will provide a capacity of users that can access transit by walking. More research will have to be done over time to assess a corridors build out adjacent to freeway to determine if these environments will transition to TOD compatible environments even as the region faces significant population growth.

We conclude by saying that the RTD light rail system classifies as a hybrid system, where stations closer to the CBD reflect TOD compatibility while stations that are further away and adjacent to U.S. Interstates do not, suggesting the existence of a feeder system. Our results showed evidence that these feeder stations typologies may not accomplish substantial VMT reduction within their adjacent neighborhoods nor improve transportation network functionality, as their existing designs facilitate existing suburban trends that have occurred for decades and may not replace auto trips through walking and additional transit rides. It is our intent that policy makers can utilize our findings as a baseline to design improved light rail systems geared towards optimizing the environmental and functionality objectives of transportation in our U.S. cities.

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APPENDIX

Appendix A: Raw Data Table

Station Typology Profile	Land Use Data									
	Residential LU (Acres)	Retail LU (Acres)	Non-Retail LU (Acres)	Industrial LU (Acres)	TOD (LU) Acres	Public Space LU (Acres)	Vacant Sapce LU (Acres)	Road/Rail LU (Acres)	Parking LU (Acres)	Recreation LU (Acres)
Littleton-Mineral	116.32	32.56	0	0	0	0	147.42	160.16	17.42	28.52
Littleton-Downtown	125.82	25.24	25.04	8.05	0.17	69.03	31.27	147.97	15.66	54.15
Oxford City of Sheridan	81.55	43.75	0	137.94	0	3.8	8.38	123.6	22.34	81.04
Englewood	78.35	69.33	10.87	108.01	8.38	19.44	21.95	160.6	11.4	14.07
Evans	126.78	22.2	4.36	78.22	0.96	3.73	59.41	136.89	5.4	64.45
I-25 Broadway	68.98	79.72	8.56	69.97	0.3	12.8	74.08	165.07	22.92	0
Louisiana-Pearl	231.92	10.72	4.5	2.38	1.44	6.55	10.7	184.07	4.31	45.81
University of Denver	192.61	3.36	3.16	0	0	98.89	4.35	176.86	8.75	14.42
Colorado	168.58	54.38	46.6	19.32	0	32.06	8.3	166.38	6.78	0
Yale	301.79	0.59	4.58	0	0	27.39	4.47	152.02	1.86	9.7
Southmoor	222.43	33.32	5.58	26.93	0	57.67	12.19	128.43	10.67	5.18
Dayton	144.98	0	0.06	0	0	0	250.22	83.53	12.39	11.22
Nine-Mile	65.44	47.07	31.95	0	0	1.16	240.92	72.31	20	23.55
Belleview	50.96	54.05	119.23	3.2	0	0	120.72	132.19	16.66	5.39
Orchard	31.11	23.89	246.79	0.1	0	3.62	39.08	115.84	30.03	11.94
Arapahoe	46.79	91.97	109.21	0	0	3	111.4	117.59	19.28	3.16
Dry Creek	50.75	22.98	171.26	2.61	0	15.68	82.77	113.37	16	26.98
County Line	5.48	174.62	74.83	10.46	0	15.63	45.13	174.49	0	1.76
Lincoln	106.82	9.93	80.81	6.07	0	7.77	136.7	90.93	14.91	48.46
Alameda	59.48	97.6	9.1	75.94	0.56	39.84	16.63	160.78	12.9	29.57
10th and Osage	77	17.29	46.77	153.8	3.73	6.48	12.35	162.42	6.96	15.6
Colfax at Auraria	50	25.78	25.15	36.81	3.72	121.44	23.13	115.36	71.02	29.99
Theater Convention	22.39	40.97	87.37	5.74	7.82	109.78	10.67	146.58	55.6	15.48
16th Street	20.5	30.46	109.45	9.28	7.47	15.3	10.58	196.21	62.41	40.74
18th Street	27.31	37.42	99.31	10.03	11.63	31.47	8.71	197.65	74.46	4.41
20th and Welton	47.66	37.09	82.04	13.2	22.93	11.54	24.32	198.44	63.91	1.27
25th and Welton	146.72	22.42	12.09	16.19	15.31	23.79	35.59	201.77	22.11	6.41
27th and Welton	177.65	16.02	8.03	12.87	7.65	41.66	31.52	194.72	9.62	2.66
30th and Downing	184.89	12.35	6.68	15.61	2.8	55.57	14.16	191.37	4.77	14.2
Invesco Field	0.33	16.39	17.22	33.12	4.5	57.2	51.64	120.81	144.12	57.07
Auraria West	20.37	21.21	12.34	63.82	4.83	89.89	36.54	95.21	123.23	34.96
Pepsi Center	17.15	16.12	15.54	5.04	4.21	38.7	49.16	140.97	130.15	85.36
Union Station	13.32	15.69	45.59	10.69	13.32	38.72	48.72	243.6	35.77	36.98
29th and Welton	188.89	12.41	7.91	10.94	3.23	50.04	17.39	192.47	5.84	13.28

Station Typology Profile	**Density and Design**					**Traffic Generation**				
	Intersection Density	**Link to Node**	**Households/ Res Acres**	**Retail Density**	**Non-Retail Density**	**Total Population**	**Total Public Sector Jobs**	**Total Retail Jobs**	**Total Non-Retail Jobs**	**Enrollment**
Littleton-Mineral	47.11	1.14	8.87	1.26	1.19	1999	0	875	70	0
Littleton-Downtown	117.14	1.48	12.17	2.44	0.88	2434	3894	776	2644	9961
Oxford City of Sheridan	84.03	1.23	5.05	0.69	0.47	1043	162	942	2202	0
Englewood	81.49	1.78	15.09	0.62	0.83	2419	657	1148	4038	0
Evans	104.41	1.72	8.34	1.42	1.01	2248	0	478	2912	0
I-25 Broadway	72.57	1.83	17.77	0.55	1.12	1917	24	1161	3522	0
Louisiana-Pearl	138.78	1.91	10.05	3.21	2.72	4393	0	740	349	0
University of Denver	101.86	2.01	9.96	5.36	0.56	4187	4	430	121	11911
Colorado	122.23	1.46	14.35	1.40	1.32	4337	353	2761	7025	925
Yale	122.23	1.38	5.42	10.17	1.13	3430	119	207	482	0
Southmoor	89.13	1.49	6.65	0.60	0.55	3035	0	1259	459	0
Dayton	39.47	1.25	12.32	0.00	1.95	3481	30	14	38	0
Nine-Mile	38.20	1.22	20.06	0.76	1.01	2475	39	849	1449	0
Belleview	30.56	1.59	28.65	0.37	0.30	1668	478	1035	10255	0
Orchard	57.30	1.25	32.50	0.25	0.16	1357	32	117	2089	2690
Arapahoe	47.11	1.37	17.10	0.13	0.28	1377	70	331	2516	500
Dry Creek	38.20	1.31	22.50	1.00	0.39	1583	1382	389	6709	0
County Line	43.29	1.48	5.84	0.85	0.48	49	32	6587	3122	0
Lincoln	38.20	1.27	11.90	1.11	0.24	2295	5	456	6030	0
Alameda	78.94	1.72	17.77	0.68	0.76	1773	603	1718	1377	0
10th and Osage	95.49	1.62	17.07	1.19	0.75	3370	2163	504	3541	0
Colfax at Auraria	94.22	1.71	51.06	1.53	0.39	4178	4353	3450	2848	37950
Theater Convention	142.60	2.05	138.70	6.99	1.20	4846	7716	14034	41129	0
16th Street	165.52	2.11	189.10	9.33	1.72	5837	9738	14276	50600	0
18th Street	180.80	2.08	157.47	7.38	2.39	7221	9932	13927	50719	0
20th and Welton	179.53	2.14	94.01	4.67	2.86	8735	7508	9358	46197	0
25th and Welton	192.26	2.09	30.82	1.33	2.67	9080	890	929	1212	0
27th and Welton	179.53	2.08	21.18	1.01	1.59	7645	403	379	461	0
30th and Downing	178.25	2.06	17.57	1.25	1.00	7291	135	263	375	0
Invesco Field	42.02	1.62	12.84	1.48	0.24	695	0	2324	1932	0
Auraria West	50.93	1.53	15.75	1.50	0.28	1588	119	2473	2756	37950
Pepsi Center	48.38	2.12	55.57	2.02	0.41	1847	2	2949	2115	0
Union Station	99.31	1.58	172.67	7.38	1.86	5757	1969	7899	16747	0
29th and Welton	183.35	2.05	17.93	1.21	1.08	7163	242	342	406	0

Station Typology Profile	Intermodal Access Variables				Transit Route Structure and Socioeconomic				
	Walk Score	Freeway	Bus Connections	Park and Ride Spots	Terminal	Transfer	Centrality	Median Income	% Renters
Littleton-Mineral	38	0	5	1227	1	0	0.830	$79,498.65	14.31%
Littleton-Downtown	83	0	7	361	0	0	0.739	$37,168.75	66.76%
Oxford City of Sheridan	72	0	1	0	0	0	0.653	$41,456.04	50.39%
Englewood	88	0	6	910	0	0	0.598	$36,328.67	71.00%
Evans	63	0	1	99	0	0	0.523	$48,518.97	50.19%
I-25 Broadway	72	1	5	1248	0	1	0.430	$49,669.34	54.52%
Louisiana-Pearl	75	1	2	0	0	0	0.482	$76,377.71	36.63%
University of Denver	69	1	2	540	0	0	0.520	$48,244.56	53.62%
Colorado	88	1	4	363	0	0	0.582	$35,649.55	62.96%
Yale	51	1	1	129	0	0	0.650	$60,999.36	29.03%
Southmoor	63	1	4	788	0	1	0.614	$74,312.96	24.07%
Dayton	34	1	0	250	0	0	0.757	$49,195.80	53.25%
Nine-Mile	57	1	13	1225	1	0	0.848	$46,351.12	53.60%
Belleview	54	1	3	59	0	0	0.679	$59,793.92	77.74%
Orchard	70	1	1	48	0	0	0.725	$89,384.42	85.01%
Arapahoe	75	1	6	1585	0	0	0.800	$82,981.43	56.00%
Dry Creek	58	1	1	235	0	0	0.854	$88,894.89	36.26%
County Line	78	1	1	388	0	0	0.939	$78,706.34	75.91%
Lincoln	31	1	2	1734	1	0	1.000	$67,729.92	78.89%
Alameda	82	0	4	302	0	0	0.432	$47,921.59	54.29%
10th and Osage	77	0	0	0	0	1	0.443	$24,504.98	72.65%
Colfax at Auraria	88	0	6	0	0	0	0.493	$60,052.82	73.98%
Theater Convention	95	0	0	0	0	0	0.521	$60,483.48	76.32%
16th Street	97	0	5	0	0	0	0.661	$49,625.00	79.63%
18th Street	97	0	8	0	0	1	0.662	$44,637.57	79.92%
20th and Welton	92	0	3	0	0	0	0.651	$39,951.97	82.21%
25th and Welton	77	0	0	0	0	0	0.726	$42,265.32	67.74%
27th and Welton	80	0	0	0	0	0	0.754	$42,408.75	64.81%
30th and Downing	83	0	5	27	1	0	0.813	$41,396.86	58.53%
Invesco Field	55	0	0	0	0	0	0.548	$69,304.23	76.13%
Auraria West	78	0	0	0	0	0	0.526	$78,598.81	73.00%
Pepsi Center	82	0	0	0	0	0	0.603	$86,698.50	57.05%
Union Station	78	0	1	0	1	0	0.662	$77,225.95	63.87%
29th and Welton	88	0	0	0	0	0	0.783	$42,259.14	61.60%

Appendix B: Factor Analysis Matrix Correlation Tables

1) Principal Component Analysis (Un-rotated)

Component Matrix[a]

	Component				
	1	2	3	4	5
Residential Land Use (Acres)	.084	-.909	.155	-.301	-.120
Retail Land Use (Acres)	-.240	.126	-.378	.725	-.143
Non Retail Land Use (Acres)	-.079	.498	-.594	-.009	-.322
Industrial Land Use (Acres)	-.151	-.038	.427	.649	.399
TOD Land Use	.781	.262	-.138	.086	.299
Public Land Use (Acres)	.303	.156	.601	-.064	-.586
Vacant Land Use (Acres)	-.593	.057	-.406	-.432	.324
Right of Way Land Use (Acres)	.817	-.218	-.133	.279	.034
Parking Land Use (Acres)	.177	.776	.390	-.149	.081
Recreation Land Use (Acres)	-.171	.330	.601	-.197	.413
Intersection Density (Nodes/Sq Mile)	.873	-.337	.030	.040	-.020
Link to Node Ratio	.816	.008	.181	.167	-.032
Households / Residential Acres	.686	.556	-.244	-.114	.029
Retail Jobs / Acre	.693	.163	-.040	-.313	-.148
Non-Retail Jobs / Acre	.713	-.264	-.333	-.167	.422

Extraction Method: Principal Component Analysis.

a. 5 components extracted.

2) Principal Component Analysis (Quartimax Rotation)

Rotated Component Matrix[a]

	Component				
	1	2	3	4	5
Residential Land Use (Acres)	.092	-.935	.265	.072	.073
Retail Land Use (Acres)	-.157	.154	-.808	-.063	-.239
Non Retail Land Use (Acres)	-.106	.435	-.473	-.094	.526
Industrial Land Use (Acres)	-.065	.073	-.065	.022	-.879
TOD Land Use	.807	.349	.030	-.141	-.023
Public Land Use (Acres)	.133	.071	.195	.870	.083
Vacant Land Use (Acres)	-.539	.040	.148	-.644	.287
Right of Way Land Use (Acres)	.860	-.145	-.203	.044	-.086
Parking Land Use (Acres)	.070	.770	.379	.269	-.014
Recreation Land Use (Acres)	-.212	.362	.639	.044	-.349
Intersection Density (Nodes/Sq Mile)	.878	-.288	.046	.153	.012
Link to Node Ratio	.790	.057	.036	.296	-.106
Households / Residential Acres	.643	.574	-.002	-.018	.332
Retail Jobs / Acre	.616	.144	.192	.179	.400
Non-Retail Jobs / Acre	.794	-.174	.137	-.450	.109

Extraction Method: Principal Component Analysis.
Rotation Method: Quartimax with Kaiser Normalization.

a. Rotation converged in 19 iterations.

Component Transformation Matrix

Component	1	2	3	4	5
1	.976	.048	.073	.169	.102
2	-.080	.983	.000	.098	.134
3	-.098	-.001	.589	.622	-.507
4	.098	.088	-.707	.129	-.683
5	.145	.155	.385	-.747	-.499

Extraction Method: Principal Component Analysis.
Rotation Method: Quartimax with Kaiser Normalization.

3) Principal Component Analysis (Equimax Rotation)

Rotated Component Matrix[a]

	Component				
	1	2	3	4	5
Residential Land Use (Acres)	-.007	.070	-.927	-.275	.152
Retail Land Use (Acres)	-.125	-.026	.514	-.541	-.435
Non Retail Land Use (Acres)	-.108	-.140	.682	-.265	.380
Industrial Land Use (Acres)	.026	.090	-.014	.151	-.869
TOD Land Use	.818	.189	.257	.135	.077
Public Land Use (Acres)	-.217	.819	-.049	.249	.204
Vacant Land Use (Acres)	-.252	-.839	.027	.076	.191
Right of Way Land Use (Acres)	.750	.402	-.062	-.289	-.011
Parking Land Use (Acres)	.036	.245	.458	.732	.094
Recreation Land Use (Acres)	-.111	-.060	-.050	.801	-.223
Intersection Density (Nodes/Sq Mile)	.716	.477	-.300	-.165	.149
Link to Node Ratio	.617	.587	-.015	.044	.030
Households / Residential Acres	.598	.203	.513	.183	.399
Retail Jobs / Acre	.467	.347	.053	.129	.521
Non-Retail Jobs / Acre	.882	-.122	-.220	-.095	.207

Extraction Method: Principal Component Analysis.
Rotation Method: Equamax with Kaiser Normalization.

a. Rotation converged in 8 iterations.

Component Transformation Matrix

Component	1	2	3	4	5
1	.816	.519	-.018	.007	.254
2	-.053	.048	.858	.495	.120
3	-.250	.531	-.370	.642	-.326
4	.077	.285	.339	-.413	-.792
5	.513	-.604	-.113	.415	-.433

Extraction Method: Principal Component Analysis.
Rotation Method: Equamax with Kaiser Normalization.

Appendix C: Station Typology Results

Station Typology Rubric

Group Number: ***1*** **Light Rail System:** ***RTD - Denver***

Classification: *Land Use Diversity*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Residential Land Use	*194.13*	Acres	*96.2094*	☐	☐	☐	☐	☐	☐	☐	☑
Retail Land Use	*19.081*	Acres	*35.85*	☐	☑	☐	☐	☐	☐	☐	☐
Non-Retail Land Use	*12.417*	Acres	*45.0582*	☐	☑	☐	☐	☐	☐	☐	☐
Industrial Land Use	*11.229*	Acres	*27.8335*	☐	☐	☑	☐	☐	☐	☐	☐
TOD Land Use	*3.06*	Acres	*3.6753*	☐	☐	☐	☐	☑	☐	☐	☐
Public Land Use	*46.265*	Acres	*32.6365*	☐	☐	☐	☐	☐	☐	☐	☑
Vacant Land Use	*16.994*	Acres	*52.9579*	☐	☑	☐	☐	☐	☐	☐	☐
Right of Way Land Use	*173.606*	Acres	*151.7841*	☐	☐	☐	☐	☐	☐	☑	☐
Parking Land Use	*9.037*	Acres	*31.7544*	☐	☑	☐	☐	☐	☐	☐	☐
Recreation Land Use	*16.581*	Acres	*24.6406*	☐	☑	☐	☐	☐	☐	☐	☐

Land Use Typology Descriptive ***Mixed Use?*** ☐ ***Dominant Land Use Types*** *Residential, Public, ROW*

Classification: *Street Network Design*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Intersection Density	*142.476*	Nodes / Sq Mi	*97.7776*	☐	☐	☐	☐	☐	☐	☑	☐
Link to Node Ratio	*1.801*		*1.6685*	☐	☐	☐	☐	☐	☐	☑	☐

Street Network Typology Descriptive	***Grid*** ☐	OR	***Cul-De-Sac/Partial-Grid*** ☑	OR	***Underdeveloped*** ☐
Typical Geography	Downtown		Suburban/Employment Centers		Town Centers

Classification: *Development Density*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Households	*14.61*	Per Acre	*37.4735*	☐	☑	☐	☐	☐	☐	☐	☐
Retail Companies	*2.798*	Per Acre	*2.3865*	☐	☐	☐	☐	☐	☑	☐	☐
Non-Retail Companies	*1.35*	Per Acre	*1.0526*	☐	☐	☐	☐	☐	☑	☐	☐

Development Density Descriptive ***Highest Density*** ☐ ***High Density*** ☐ ***Varied Density*** ☑ ***Low Density*** ☐ ***Lowest Density*** ☐

Typology Result: *Variable Density Suburban Centers*

Ridership	*2,776*
Rank	***4th***
Adjusted Ridership	*4,362*
Rank	***3rd***

	Adjusted Ridership	Ridership	Freeway	Station
1	***5069***	*3664*	☐	*30th and Downing*
2	***4879***	*583*	☐	*29th and Welton*
3	***4860***	*826*	☐	*27th and Welton*
4	***6474***	*1143*	☐	*25th and Welton*
5	***5278***	*5253*	☑	*Colorado*
6	***5438***	*5438*	☑	*Southmoor*
7	***3853***	*3853*	☐	*Littleton-Downtown*
8	***4096***	*4045*	☑	*University of Denver*
9	***1599***	*1512*	☑	*Yale*
10	***2069***	*1439*	☑	*Louisiana-Pearl*

Station Typology Rubric

Group Number: *2* **Light Rail System:** *RTD - Denver*

Classification: *Land Use Diversity*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Residential Land Use	*26.236*	Acres	*96.2094*	☐	☑	☐	☐	☐	☐	☐	☐
Retail Land Use	*32.326*	Acres	*35.85*	☐	☐	☐	☐	☑	☐	☐	☐
Non-Retail Land Use	*84.752*	Acres	*45.0582*	☐	☐	☐	☐	☐	☐	☑	☐
Industrial Land Use	*9.788*	Acres	*27.8335*	☐	☐	☑	☐	☐	☐	☐	☐
TOD Land Use	*12.634*	Acres	*3.6753*	☐	☐	☐	☐	☐	☐	☐	☑
Public Land Use	*41.362*	Acres	*32.6365*	☐	☐	☐	☐	☐	☐	☑	☐
Vacant Land Use	*20.6*	Acres	*52.9579*	☐	☐	☑	☐	☐	☐	☐	☐
Right of Way Land Use	*196.496*	Acres	*151.7841*	☐	☐	☐	☐	☐	☐	☐	☑
Parking Land Use	*58.43*	Acres	*31.7544*	☐	☐	☐	☐	☐	☐	☐	☑
Recreation Land Use	*19.776*	Acres	*24.6406*	☐	☐	☐	☑	☐	☐	☐	☐

Land Use Typology Descriptive ***Mixed Use?*** ☑ ***Dominant Land Use Types*** *TOD, Parking, ROW*

Classification: *Street Network Design*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Intersection Density	*153.552*	Nodes / Sq Mi	*97.7776*	☐	☐	☐	☐	☐	☐	☐	☑
Link to Node Ratio	*1.992*		*1.6685*	☐	☐	☐	☐	☐	☐	☐	☑

Street Network Typology Descriptive	***Grid*** ☑	OR	***Cul-De-Sac/Partial-Grid*** ☐	OR	***Underdeveloped*** ☐
Typical Geography	Downtown		Suburban/Employment Centers		Town Centers

Classification: *Development Density*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Households	*150.39*	Per Acre	*37.4735*	☐	☐	☐	☐	☐	☐	☑	☐
Retail Companies	*7.15*	Per Acre	*2.3865*	☐	☐	☐	☐	☐	☐	☐	☑
Non-Retail Companies	*2.006*	Per Acre	*1.0526*	☐	☐	☐	☐	☐	☐	☐	☑

Development Density Descriptive ***Highest Density*** ☑ ***High Density*** ☐ ***Varied Density*** ☐ ***Low Density*** ☐ ***Lowest Density*** ☐

Typology Result: ***High Density Mixed Use Downtown***

Ridership	*6,684*
Rank	***1st***
Adjusted Ridership	*23,278*
Rank	***1st***

	Adjusted Ridership	Ridership	Freeway	Station
1	***31,875***	*17,460*	☐	*16th Street*
2	***26,480***	*6,994*	☐	*18th Street*
3	***18,473***	*831*	☐	*20th and Welton*
4	***8,995***	*3,855*	☐	*Union Station*
5	***30,565***	*4,280*	☐	*Theater Convention Center*
6			☐	
7			☐	
8			☐	
9			☐	
10			☐	

Station Typology Rubric

Group Number: ***3*** **Light Rail System:** ***RTD - Denver***

Classification: *Land Use Diversity*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Residential Land Use	*57.999*	Acres	*96.2094*	☐	☐	☑	☐	☐	☐	☐	☐
Retail Land Use	*32.326*	Acres	*35.85*	☐	☐	☐	☐	☐	☐	☑	☐
Non-Retail Land Use	*40.939*	Acres	*45.0582*	☐	☐	☑	☐	☐	☐	☐	☐
Industrial Land Use	*14.991*	Acres	*27.8335*	☐	☐	☐	☐	☐	☐	☑	☐
TOD Land Use	*3.119*	Acres	*3.6753*	☐	☐	☐	☐	☑	☐	☐	☐
Public Land Use	*39.332*	Acres	*32.6365*	☐	☐	☐	☐	☐	☐	☐	☑
Vacant Land Use	*35.327*	Acres	*52.9579*	☐	☐	☑	☐	☐	☐	☐	☐
Right of Way Land Use	*138.171*	Acres	*151.7841*	☐	☐	☐	☑	☐	☐	☐	☐
Parking Land Use	*55.044*	Acres	*31.7544*	☐	☐	☐	☐	☐	☐	☑	☐
Recreation Land Use	*41.211*	Acres	*24.6406*	☐	☐	☐	☐	☐	☐	☐	☑

Land Use Typology Descriptive ***Mixed Use?*** ☐ ***Dominant Land Use Types*** *Public, Recreation, Retail, Parking*

Classification: *Street Network Design*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Intersection Density	*75.25*	Nodes / Sq Mi	*97.7776*	☐	☐	☐	☑	☐	☐	☐	☐
Link to Node Ratio	*1.69*		*1.6685*	☐	☐	☐	☐	☑	☐	☐	☐

Street Network Typology Descriptive	***Grid*** ☐	OR	***Cul-De-Sac/Partial-Grid*** ☑	OR	***Underdeveloped*** ☐
Typical Geography	Downtown		Suburban/Employment Centers		Town Centers

Classification: *Development Density*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Households	*21.63*	Per Acre	*37.4735*	☐	☐	☑	☐	☐	☐	☐	☐
Retail Companies	*1.17*	Per Acre	*2.3865*	☐	☐	☑	☐	☐	☐	☐	☐
Non-Retail Companies	*0.63*	Per Acre	*1.0526*	☐	☑	☐	☐	☐	☐	☐	☐

Development Density Descriptive ***Highest Density*** ☐ ***High Density*** ☐ ***Varied Density*** ☐ ***Low Density*** ☑ ***Lowest Density*** ☐

Typology Result: *Low Density Retail and Entertainment Centers*

Ridership	*5,043*
Rank	***2nd***
Adjusted Ridership	*9,716*
Rank	***2nd***

	Adjusted Ridership	Ridership	Freeway	Station
1	***6,207***	*453*	☐	*Invesco Field*
2	***6,730***	*788*	☐	*Pepsi Center*
3	***27,446***	*17,927*	☐	*Colfax at Auraria*
4	***13,841***	*1,201*	☐	*Auraria at West Campus*
5	***5,495***	*5,468*	☐	*Englewood*
6	***8,528***	*3,278*	☐	*10th and Osage*
7	***15,063***	*12,711*	☑	*I-25 Broadway*
8	***10,825***	*5,724*	☐	*Alameda*
9	***1,183***	*1,044*	☐	*Oxford City of Sheridan*
10	***1,838***	*1,838*	☐	*Evans*

Station Typology Rubric

Group Number: **4**

Light Rail System: *RTD - Denver*

Classification: *Land Use Diversity*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Residential Land Use	*68.7389*	Acres	*96.2094*	☐	☐	☑	☐	☐	☐	☐	☐
Retail Land Use	*50.7856*	Acres	*35.85*	☐	☐	☐	☐	☐	☐	☐	☑
Non-Retail Land Use	*92.6822*	Acres	*45.0582*	☐	☐	☐	☐	☐	☐	☐	☑
Industrial Land Use	*2.4933*	Acres	*27.8335*	☐	☑	☐	☐	☐	☐	☐	☐
TOD Land Use	*0*	Acres	*3.6753*	☑	☐	☐	☐	☐	☐	☐	☐
Public Land Use	*5.2067*	Acres	*32.6365*	☐	☑	☐	☐	☐	☐	☐	☐
Vacant Land Use	*130.4844*	Acres	*52.9579*	☐	☐	☐	☐	☐	☐	☐	☑
Right of Way Land Use	*117.8233*	Acres	*151.7841*	☐	☑	☐	☐	☐	☐	☐	☐
Parking Land Use	*16.2989*	Acres	*31.7544*	☐	☐	☑	☐	☐	☐	☐	☐
Recreation Land Use	*17.8867*	Acres	*24.6406*	☐	☐	☐	☑	☐	☐	☐	☐

Land Use Typology Descriptive — ***Mixed Use?*** ☐ — ***Dominant Land Use Types*** *Retail, Non-Retail, Vacant*

Classification: *Street Network Design*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Intersection Density	*42.16*	Nodes / Sq Mi	*97.7776*	☐	☑	☐	☐	☐	☐	☐	☐
Link to Node Ratio	*1.32*		*1.6685*	☐	☑	☐	☐	☐	☐	☐	☐

Street Network Typology Descriptive	***Grid*** ☐	OR	***Cul-De-Sac/Partial-Grid*** ☐	OR	***Underdeveloped*** ☑
Typical Geography	Downtown		Suburban/Employment Centers		Town Centers

Classification: *Development Density*

Variable	Value	Units	Average	None	Lowest	Low	Below Average	Average	Above Average	High	Highest
				Level of Presence							
Households	*17.7489*	Per Acre	*37.4735*	☐	☐	☑	☐	☐	☐	☐	☐
Retail Companies	*0.6367*	Per Acre	*2.3865*	☐	☑	☐	☐	☐	☐	☐	☐
Non-Retail Companies	*0.6667*	Per Acre	*1.0526*	☐	☐	☑	☐	☐	☐	☐	☐

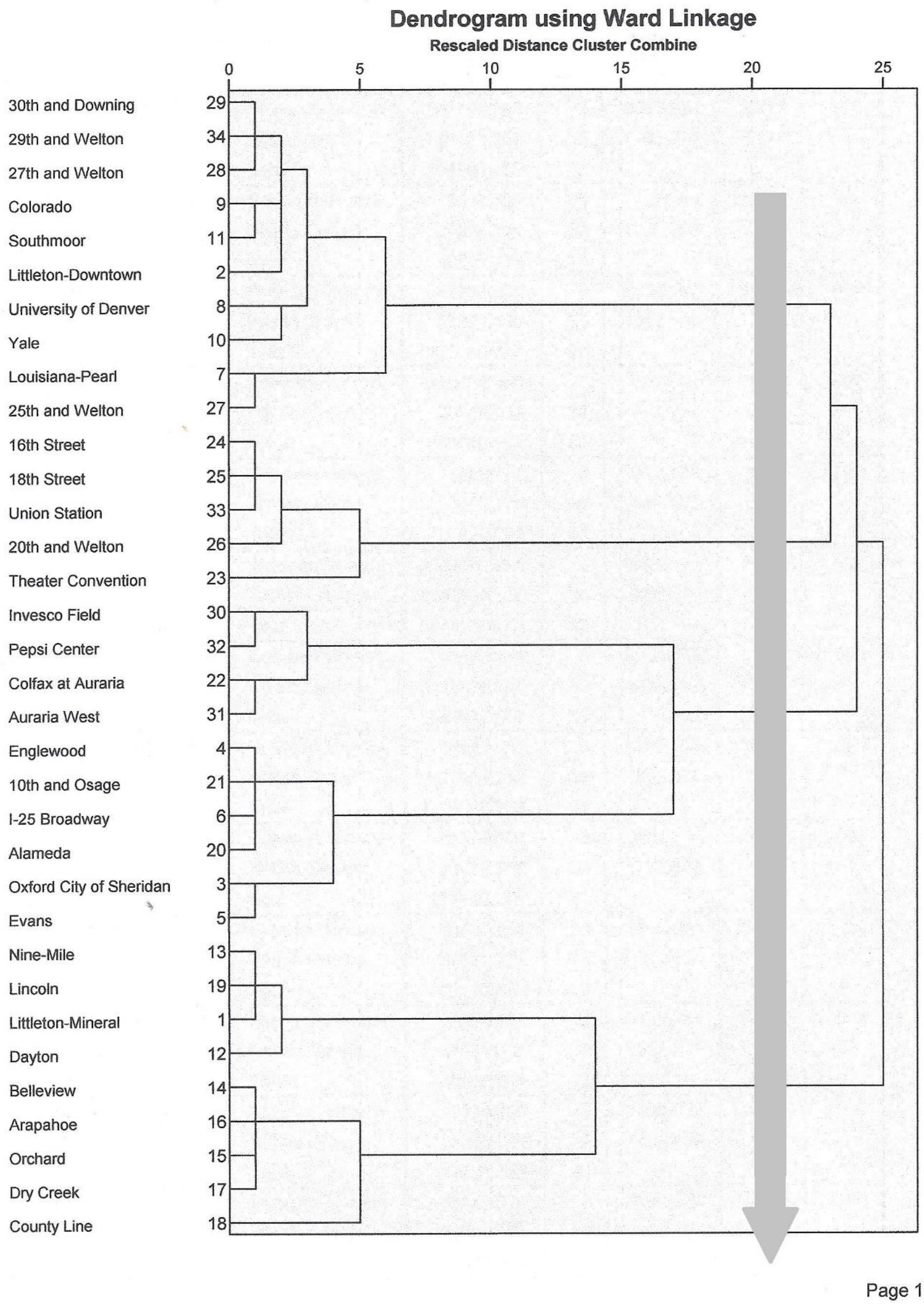
Development Density Descriptive — ***Highest Density*** ☐ ***High Density*** ☐ ***Varied Density*** ☐ ***Low Density*** ☐ ***Lowest Density*** ☑

Typology Result: ***Low Density Commercial Centers***

Ridership	*2,777*
Rank	***3rd***
Adjusted Ridership	*2,777*
Rank	***4th***

	Adjusted Ridership	Ridership	Freeway	Station
1	***6,315***	*6,315*	☑	*Nine-Mile*
2	***4,012***	*4,012*	☑	*Lincoln*
3	***1,059***	*1,059*	☑	*Dayton*
4	***1,478***	*1,478*	☑	*Belleview*
5	***2,698***	*2,698*	☑	*Arapahoe*
6	***1,250***	*1,250*	☑	*Orchard*
7	***1,750***	*1,750*	☑	*Dry-Creek*
8	***1,541***	*1,541*	☑	*County Line*
9	***4,886***	*4,886*	☐	*Littleton-Mineral*
10			☐	

Appendix D: Station Typology Dendrogram



Appendix E: Station Typology Descriptives and ANOVA

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval		Minimum	Maximum
						Lower Bound	Upper Bound		
Residential Land Use (Acres)	1	10	194	49	16	159	229	126	302
	2	5	26	13	6	10	42	13	48
	3	10	58	38	12	31	85	0	127
	4	9	69	45	15	34	103	5	145
	Total	*34*	*96*	*76*	*13*	*70*	*123*	*0*	*302*
Retail Land Use (Acres)	1	10	19	16	5	8	30	1	54
	2	5	32	10	4	20	45	16	41
	3	10	41	30	10	19	63	16	98
	4	9	51	54	18	9	92	0	175
	Total	*34*	*36*	*34*	*6*	*24*	*48*	*0*	*175*
Non Retail Land Use (Acres)	1	10	12	14	4	3	22	3	47
	2	5	85	24	11	55	115	46	109
	3	10	15	13	4	6	24	0	47
	4	9	93	81	27	31	155	0	247
	Total	*34*	*45*	*57*	*10*	*25*	*65*	*0*	*247*
Industrial Land Use (Acres)	1	10	11	9	3	5	18	0	27
	2	5	10	3	1	6	13	6	13
	3	10	76	47	15	43	110	5	154
	4	9	2	4	1	0	5	0	10
	Total	*34*	*28*	*40*	*7*	*14*	*42*	*0*	*154*
TOD Land Use	1	10	3	5	2	0	7	0	15
	2	5	13	6	3	5	20	7	23
	3	10	3	3	1	1	5	0	8
	4	9	0	0	0	0	0	0	0
	Total	*34*	*4*	*5*	*1*	*2*	*6*	*0*	*23*
Households / Residential Acres	1	10	15	8	2	9	20	5	31
	2	5	150	37	16	105	196	94	189
	3	10	22	17	5	9	34	5	56
	4	9	18	9	3	11	25	6	33
	Total	34	37	51	9	20	55	5	189
Non-Retail Jobs / Acre	1	10	1	1	0	1	2	1	3
	2	5	2	1	0	1	3	1	3
	3	10	1	0	0	0	1	0	1
	4	9	1	1	0	0	1	0	2
	Total	34	1	1	0	1	1	0	3
Retail Jobs / Acre	1	10	3	3	1	1	5	1	10
	2	5	7	2	1	5	9	5	9
	3	10	1	1	0	1	2	1	2
	4	9	1	0	0	0	1	0	1
	Total	34	2	3	0	1	3	0	10

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval		Minimum	Maximum
						Lower Bound	Upper Bound		
Public Land Use (Acres)	1	10	46	26	8	28	65	7	99
	2	5	41	40	18	-8	91	12	110
	3	10	39	40	13	11	68	4	121
	4	9	5	6	2	0	10	0	16
	Total	*34*	*33*	*33*	*6*	*21*	*44*	*0*	*121*
Right of Way Land Use (Acres)	1	10	174	24	8	156	191	128	202
	2	5	196	34	15	154	239	147	244
	3	10	138	24	8	121	155	95	165
	4	9	118	34	11	92	144	72	174
	Total	*34*	*152*	*39*	*7*	*138*	*166*	*72*	*244*
Vacant Land Use (Acres)	1	10	17	12	4	9	25	4	36
	2	5	21	17	8	0	42	9	49
	3	10	35	22	7	19	51	8	74
	4	9	130	75	25	73	188	39	250
	Total	*34*	*53*	*62*	*11*	*31*	*75*	*4*	*250*
Parking Land Use (Acres)	1	10	9	6	2	5	13	2	22
	2	5	58	14	6	41	76	36	74
	3	10	55	57	18	14	96	5	144
	4	9	16	8	3	10	22	0	30
	Total	*34*	*32*	*38*	*6*	*19*	*45*	*0*	*144*
Recreation Land Use (Acres)	1	10	17	18	6	3	30	0	54
	2	5	20	18	8	-3	42	1	41
	3	10	41	29	9	20	62	0	85
	4	9	18	15	5	6	30	2	48
	Total	*34*	*25*	*23*	*4*	*17*	*33*	*0*	*85*
Intersection Density (Nodes/Sq Mile)	1	10	142	38	12	116	169	89	192
	2	5	154	34	15	111	196	99	181
	3	10	75	22	7	60	91	42	104
	4	9	42	8	3	36	48	31	57
	Total	*34*	*98*	*52*	*9*	*80*	*116*	*31*	*192*
Link to Node Ratio	1	10	1.80	0.31	0.10	1.58	2.02	1.38	2.09
	2	5	1.99	0.23	0.10	1.70	2.28	1.58	2.14
	3	10	1.69	0.23	0.07	1.53	1.85	1.23	2.12
	4	9	1.32	0.14	0.05	1.21	1.43	1.14	1.59
	Total	*34*	*1.67*	*0.32*	*0.06*	*1.56*	*1.78*	*1.14*	*2.14*

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Residential Land Use (Acres)	Between Groups	141757.830	3	47252.610	27.697	.000
	Within Groups	51182.328	30	1706.078		
	Total	192940.159	33			
Retail Land Use (Acres)	Between Groups	5140.703	3	1713.568	1.509	.232
	Within Groups	34068.710	30	1135.624		
	Total	39209.413	33			
Non Retail Land Use (Acres)	Between Groups	47985.261	3	15995.087	8.302	.000
	Within Groups	57801.480	30	1926.716		
	Total	105786.740	33			
Industrial Land Use (Acres)	Between Groups	33622.450	3	11207.483	16.523	.000
	Within Groups	20348.533	30	678.284		
	Total	53970.983	33			
TOD Land Use	Between Groups	529.743	3	176.581	12.031	.000
	Within Groups	440.308	30	14.677		
	Total	970.051	33			
Public Land Use (Acres)	Between Groups	9457.891	3	3152.630	3.478	.028
	Within Groups	27191.312	30	906.377		
	Total	36649.203	33			
Vacant Land Use (Acres)	Between Groups	75370.962	3	25123.654	14.473	.000
	Within Groups	52075.297	30	1735.843		
	Total	127446.259	33			
Right of Way Land Use (Acres)	Between Groups	26990.891	3	8996.964	11.070	.000
	Within Groups	24381.792	30	812.726		
	Total	51372.683	33			
Parking Land Use (Acres)	Between Groups	16292.651	3	5430.884	5.310	.005
	Within Groups	30684.041	30	1022.801		
	Total	46976.691	33			
Recreation Land Use (Acres)	Between Groups	3924.215	3	1308.072	2.810	.056
	Within Groups	13962.934	30	465.431		
	Total	17887.149	33			
Intersection Density (Nodes/Sq Mile)	Between Groups	68449.074	3	22816.358	31.059	.000
	Within Groups	22038.105	30	734.604		
	Total	90487.179	33			
Link to Node Ratio	Between Groups	1.796	3	.599	10.730	.000
	Within Groups	1.674	30	.056		
	Total	3.469	33			
Freeway in Corridor (Binary)	Between Groups	3.946	3	1.315	9.201	.000
	Within Groups	4.289	30	.143		
	Total	8.235	33			
Households / Residential Acres	Between Groups	74989.467	3	24996.489	81.455	.000
	Within Groups	9206.193	30	306.873		
	Total	84195.660	33			
Retail Jobs / Acre	Between Groups	157.553	3	52.518	16.893	.000
	Within Groups	93.263	30	3.109		
	Total	250.816	33			
Non-Retail Jobs / Acre	Between Groups	8.590	3	2.863	7.975	.000
	Within Groups	10.771	30	.359		
	Total	19.360	33			

Descriptives

Adjusted Ridership per Day

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	10	4361.50	1516.369	479.518	3276.76	5446.24	1599	6474
2	5	23277.60	9544.026	4268.218	11427.13	35128.07	8995	31875
3	10	9715.60	7720.976	2441.587	4192.35	15238.85	1183	27446
4	9	2776.56	1872.494	624.165	1337.23	4215.88	1059	6315
Total	34	8298.47	8740.353	1498.958	5248.82	11348.12	1059	31875

ANOVA

Adjusted Ridership per Day

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1571375432	3	523791810.7	16.547	.000
Within Groups	949619182.3	30	31653972.74		
Total	2520994614	33			

Appendix F: Final Regression Model Statistics

Correlations

		Total Population in Corridor	Total # of Jobs	# of Jobs in Public Sector	# of Retail Jobs	# of Non Retail Jobs	Walk Score	PctRent	Adjusted Ridership per Day	Freeway in Corridor (Binary)	Normalized Accessibility	Cluster Analysis Group Number
Total Population in Corridor	Pearson Correlation	1	.440**	.471**	.357*	.445**	.455**	.191	.380*	-.374*	.009	-.677**
	Sig. (2-tailed)		.009	.005	.038	.008	.007	.278	.027	.029	.959	.000
	N	34	34	34	34	34	34	34	34	34	34	34
Total # of Jobs	Pearson Correlation	.440**	1	.946**	.952**	.996**	.516**	.458**	.807**	-.318	-.089	-.132
	Sig. (2-tailed)	.009		.000	.000	.000	.002	.007	.000	.067	.616	.457
	N	34	34	34	34	34	34	34	34	34	34	34
# of Jobs in Public Sector	Pearson Correlation	.471**	.946**	1	.877**	.928**	.566**	.448**	.850**	-.406*	-.135	-.194
	Sig. (2-tailed)	.005	.000		.000	.000	.000	.008	.000	.017	.448	.271
	N	34	34	34	34	34	34	34	34	34	34	34
# of Retail Jobs	Pearson Correlation	.357*	.952**	.877**	1	.925**	.551**	.444**	.815**	-.334	-.108	-.123
	Sig. (2-tailed)	.038	.000	.000		.000	.001	.008	.000	.054	.543	.488
	N	34	34	34	34	34	34	34	34	34	34	34
# of Non Retail Jobs	Pearson Correlation	.445**	.996**	.928**	.925**	1	.482**	.450**	.773**	-.287	-.073	-.119
	Sig. (2-tailed)	.008	.000	.000	.000		.004	.008	.000	.099	.683	.504
	N	34	34	34	34	34	34	34	34	34	34	34
Walk Score	Pearson Correlation	.455**	.516**	.566**	.551**	.482**	1	.444**	.577**	-.497**	-.374*	-.469**
	Sig. (2-tailed)	.007	.002	.000	.001	.004		.009	.000	.003	.029	.005
	N	34	34	34	34	34	34	34	34	34	34	34
PctRent	Pearson Correlation	.191	.458**	.448**	.444**	.450**	.444**	1	.419*	-.264	-.016	.107
	Sig. (2-tailed)	.278	.007	.008	.008	.008	.009		.014	.132	.928	.549
	N	34	34	34	34	34	34	34	34	34	34	34
Adjusted Ridership per Day	Pearson Correlation	.380*	.807**	.850**	.815**	.773**	.577**	.419*	1	-.434*	-.357*	-.134
	Sig. (2-tailed)	.027	.000	.000	.000	.000	.000	.014		.010	.038	.450
	N	34	34	34	34	34	34	34	34	34	34	34
Freeway in Corridor (Binary)	Pearson Correlation	-.374*	-.318	-.406*	-.334	-.287	-.497**	-.264	-.434*	1	.256	.235
	Sig. (2-tailed)	.029	.067	.017	.054	.099	.003	.132	.010		.144	.182
	N	34	34	34	34	34	34	34	34	34	34	34
Normalized Accessibility	Pearson Correlation	.009	-.089	-.135	-.108	-.073	-.374*	-.016	-.357*	.256	1	.269
	Sig. (2-tailed)	.959	.616	.448	.543	.683	.029	.928	.038	.144		.124
	N	34	34	34	34	34	34	34	34	34	34	34
Cluster Analysis Group Number	Pearson Correlation	-.677**	-.132	-.194	-.123	-.119	-.469**	.107	-.134	.235	.269	1
	Sig. (2-tailed)	.000	.457	.271	.488	.504	.005	.549	.450	.182	.124	
	N	34	34	34	34	34	34	34	34	34	34	34

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Variables Entered/Removed [a,b]

Model	Variables Entered	Variables Removed	Method
1	# of Jobs in Public Sector, Walk Score [c]	-	Enter

a. Dependent Variable: Adjusted Ridership per Day

b. Linear Regression through the Origin

c. All requested variables entered.

Model Summary

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.929[a]	.863	.855	4557.773

a. Predictors: # of Jobs in Public Sector, Walk Score

b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explains by regression. This CANNOT be compared to R Square.

ANOVA[a,b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4197646002	2	2098823001	101.035	.000[c]
	Residual	664745491.7	32	20773296.62		
	Total	4862391494[d]	34			

a. Dependent Variable: Adjusted Ridership per Day

b. Linear Regression through the Origin

c. Predictors: # of Jobs in Public Sector, Walk Score

d. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	Walk Score	63.842	12.899	.398	4.949	.000
	# of Jobs in Public Sector	2.362	.297	.639	7.949	.000

a. Dependent Variable: Adjusted Ridership per Day

b. Linear Regression through the Origin